MANAGERIAL BRIEFING
INDUSTRIAL ENGINEERING APPLICATIONS IN SHIPBUILDING

Property of

____

____

____

Presented By:
AMERICAN INSTITUTE OF INDUSTRIAL ENGINEERS
25 TECHNOLOGY PARK/ATLANTA
NORCROSS, GA 30092

In Cooperation With:
U.S. DEPARTMENT OF COMMERCE
MARITIME ADMINISTRATION
AND
BATH IRON WORKS CORPORATION

Report Documentation Page			*Form Approved* *OMB No. 0704-0188*

Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.

1. REPORT DATE **1982**	2. REPORT TYPE	3. DATES COVERED **00-00-1982 to 00-00-1982**

4. TITLE AND SUBTITLE **Managerial Briefing. Industrial Engineering Applications in Shipbuilding**	5a. CONTRACT NUMBER
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Naval Surface Warfare Center CD,Code 2230 -Design Integration Tower,9500 MacArthur Blvd Bldg 192 Room 128,Bethesda,MD,20817-5700**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**		**177**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

INDUSTRIAL ENGINEERING APPLICATIONS IN SHIPBUILDING

AMERICAN INSTITUTE OF INDUSTRIAL ENGINEERS
25 TECHNOLOGY PARK/ ATLANTA NORCROSS, GEORGIA 30092

TABLE OF CONTENTS

Page

OVERVIEW

OVERVIEW

MANAGERIAL BRIEFING ON INDUSTRIAL ENGINEERING

Overview

Provisions of the Merchant Marine Act of 1970 charged the Secretary of Commerce with the responsibility to "collaborate with . . . shipbuilders in developing plans for the economical construction of vessels." (Section 212(c)). To accomplish this task, the National Shipbuilding Research Program was established by the Maritime Administration with the responsibility to develop improved technical information and procedures for use by U.S. Shipyards. The purpose of these improved procedures was to reduce the cost and time for building ships. Specifically, the ship production committee challenged the industry to (1) develop the role of Industrial Engineering in shipbuilding; (2) implement an improved Industrial Engineering capacity; and (3) assist the U.S. shipyards in formulating national standards for shipbuilding.

To initiate a cooperative industry program in Industrial Engineering, a planning workshop was held in Atlanta, Georgia in February 1978. This workshop was to identify preliminary projects best suited for cooperative development. The American Institute of Industrial Engineers, Inc. assisted in the preparation and the conduct of this workshop.

Participants in this workshop drew an important conclusion from their meeting. The critical problems facing each individual shipyard were in fact problems common to all of the shipyards. From this recognition of the universal nature of problems among shipyards, two further conclusions were drawn. First, there was an urgent need to promote the application of Industrial Engineering Technology within the shipbuilding industry. Second, there was a wide discrepancy between the firms represented with regard to the placement and assignment of duties for

professional industrial engineers.

One of the first common problems faced by firms within the shipbuilding industry is the establishment of job standards for the basic tasks of shipbuilding. Valid job standards can be used in developing better cost estimates when preparing bids. Further, job standards provide the basis for controlling costs during production and evaluating the impact of proposed design changes. The formulation of job standards has been a traditional function of industrial engineering, and the need for such standards dictates the need for the industrial engineering function. However, since only a portion of the industry is actively engaged in establishing job standards, it was felt that the entire industry could benefit from information on the effectiveness of this activity. As one can see with the function of establishing job standards, the conclusions drawn by the workshop participants rang true. There was a common problem faced by all shipyards which could be attacked through industrial engineering techniques. And there was a wide variation among firms in their application of industrial engineers to solve the problem.

Similar problems were also identified by the workshop participants. Problems in areas of scheduling material flow, balancing shop loading schedules, and quality assurance all could fit the framework of the previously cited conclusions. Consequently, it became evident to the participants of this workshop that an industry-wide effort was necessary to learn about how to use industrial engineers more effectively in shipbuilding. It was determined that the initial thrust of this effort would be the preparation and presentation of a management briefing on the functions of industrial engineering. Further, this briefing should be presented to *all* shipbuilding firms. The contract for the preparation and presentation of this briefing was awarded to the American Institute of Industrial Engineers, Inc.

The objectives of this briefing are fourfold:

1. Understand what is meant by productivity and what cost reductions and profit improvements are possible through increasing productivity.
2. Recognize what functions are within the realm of industrial engineering.
3. Examine how the industrial engineer can contribute to productivity savings by performing within those functions.
4. Identify the sequence and feasibility of implementing industrial engineering functions and discuss the possible payoffs which might be achieved in shipbuilding.

In order to accomplish these objectives, the management briefing will cover:

- Industrial Engineering
  - Development of the Profession
- Industrial Engineering Functions
  - Systems and Technology
  - Systems and Human Effort
- From Here to There

It is hoped that as a result of the briefing each manager will gain an enhanced appreciation for the importance of improving productivity in each shipyard. Further, it is hoped that each manager will gain a better appreciation of how the industrial engineer can contribute to productivity improvements, while performing the functions required in shipbuilding. Finally, the briefing will

provide information on how more extensive industrial engineering activities could be phased into the shipbuilding operation.

Industrial Engineering is concerned with the design, improvement, and installation of integrated systems of people, material, equipment, and energy. It draws upon specialized knowledge and skills in the mathematical, physical, and social sciences together with principles and methods of engineering analysis and design to specify, predict, and evaluate the results obtained from such systems. Given this official definition of industrial engineering adopted by the American Institute of Industrial Engineers, Inc., the objective of industrial engineering in shipbuilding is to support the production of ships in a manner that achieves the goals and objectives of management.

When referring to the goals of management, it is assumed that these goals could be paraphrased as (a) to acquire the desired number of contracts through the ability to bid at a competitive price, (b) to provide ships at a cost which meets or exceeds all profit targets, and (c) to meet all quality and delivery time targets. Satisfying these goals would provide the customer with a dependable product, delivered on time, and at a fair price, while providing a fair return to the shipyard. The Board establishes the objectives of sales, profit, and product mix required to achieve their overall corporate goals. To translate these objectives into guides for marketing and into plans for productions certain questions must be answered. These questions relate to factors such as the shipyard's available facilities, labor force and capital requirements. For example,

Facilities

- How much capacity is available and at what time?
- What kind of capacity is available? Welding shop, drydock, outfitting?
- What increased capacity is available through expansion, through real-location, or through using outside suppliers or subcontractors?

Labor Force

How many people are required?

What skill level mix must be available?

How long would it take to hire and train workers for a specific task?

What flexibility is possible in assigning tasks?

Is a fluctuating labor force a better alternative than a level workload?

Capital

What will be the capital requirements to generate the targeted level of business?

When will this capital be required?

What will be the payoff of the proposed business strategies?

These questions must be answered in developing the strategic plan for shipyard operation. The industrial engineer has the training and experience to provide the necessary data and analysis to answer these longterm strategic questions as well as to solve immediate problems. However, by allowing the industrial engineer to serve management at the strategic planning level, the task of implementing these strategic plans to achieve the objectives of acquiring business, reducing costs, and meeting quality and time targets is simplified. There is a longterm benefit of integrating industrial engineering functions into the strategic plans of the shipyard.

Industrial engineering techniques will contribute to the achievement of both current and future profitability targets. The industrial engineering techniques which drive the profit improvement program flow directly from the functions of industrial engineering. For example, one of the functions of industrial engineering is work methods and methods engineering. Without job standards and work methods little definitive information is available on what resources must be allocated to complete a specific task. Gross, aggregate

measures are inadequate for planning and controlling complex production operations.

Work measurement is just one of the integrated functions of industrial engineering that could impact shipyard operation. During this briefing those industrial engineering functions with an anticipated payoff for shipyard operation will be examined. First, however, the development of the profession of industrial engineering will be considered. This historical perspective will demonstrate the parallel between the development of the profession and the application of industrial engineering functions to industries such as shipbuilding.

INDUSTRIAL ENGINEERING
DEVELOPMENT

INDUSTRIAL ENGINEERING
DEVELOPMENT

MANAGEMENT BRIEFING ON INDUSTRIAL ENGINEERING

INDUSTRIAL ENGINEERING

Development of the Profession

Industrial Engineering as a profession developed from the demand for techniques to improve productivity in the increasingly complex industrial processes and organizations evolving from the industrial revolution. As in most professions, industrial engineering emerged as a unique entity when both the demand for the development of these techniques broadened sufficiently to create the necessary base for the evolution of a profession. A profession must have (1) intellectual activities which are learned and practical, (2) teachable techniques, (3) organizational structure which is strong, and (4) motivational forces which are alturistic (A. Flexner, 1915). As a profession is composed of a set of techniques and activities, the initial development of the activities and techniques led to the final development of industrial engineering. The roots of industrial engineering were planted by the best known economists of the 18th century. An absent-minded professor at the University of Glasgow, Adam Smith, in 1776 stated his famous idea that "the manager should conduct his affairs so as to maximize his own personal profit with the assurance that although he intends only his own gain he is in this as in many other cases lead by an invisible hand to promote an end which is no part of his intention . . . By pursuing his own interest he frequently promotes that of society more effectually than when he really intends to promote it." Thus, Adam Smith succinctly stated the goal of managers since that time, to maximize profit or at least return a satisfactory profit on invested capital. This principle served as the basis for the development of engineering economy, a major function of industrial engineering.

In order to earn a satisfactory profit on the firm's invested capital, it was necessary to know the cost of each manufacturing operation. James Watt, the inventor of reknown, developed for his firm of Boulton, Watt and Co., a cost accounting system. Knowing what each item cost, it was then possible to divide labor in order to produce things in the most efficient manner. Division of labor reached a high degree of development in Watt's factory. Further, the products and methods of production were standardized through management planning to maintain control over manufacturing costs.

Many workers in Watt's factory were put on piece rates. Records of production were kept in elaborate fashion. These forerunners of time studies were used to develop mathematical formulas relating elements of manufacturing tasks to performance time. As happens even today, however, problems arose over the time standards used to set the piece rates and the workers at Boulton, Watt went on strike in 1791 over a dispute in production rates. Watt's Soho Foundry was important for two major reasons. First, it marked the early discovery of the immense importance of separating the planning of production from the work of production itself. Second, it put on a rational basis the twin problems of motivation and control of the manufacturing organization.

Problems of manufacturing began more and more to attract the attention of the scientific community. Charles Babbage (1792-1871), Professor of Mathematics at Cambridge University, published an 1832 essay on the "Economy of Machinery in Manufactures," which was widely read and admired for many years. He saw the importance of collecting data in an orderly fashion as a basis for making decisions. He tackled problems of work methods, performance times, cost reporting, cost reduction, and incentive. He proposed profit sharing plans to demonstrate to employees that they shared a community of interest with management. He also

pointed out many of the problems which would attend such plans.

Studying the manufacturing system was a necessity. In the beginning of the 20th century the factory system had become a way of life. The urban populace depended upon wages as a means of making a living and upon products made in factories. This dependency on manufacturing created challenges which stimulated people who could question custom and routine. These people met challenges through creatively and scientifically studying the problems and proposing startling revisions in work methods. Such an individual was Frederick W. Taylor. He began a pattern which eventually established him in the role of the “Father of Scientific Management.” His relentless imposition of his ideas on others also earned him the name “Speedy” along with the sincere hatred of many workmen who were controlled by his schemes.

Taylor did leave a great legacy to industry. His concept and methods of breaking a job into its fundamental elements allowed those elements to be individually studied and improved. He appears today as a massive and courageous innovator who provided industry with necessary methodology to study the manufacturing process. The outstanding features of his thought were: (1) traditional rules of thumb should be abandoned; (2) activities formerly left to accident should become subject to planning; (3) work methods can no longer be left to the workers; (4) management must control work methods and output through wage payment plan; and (5) work methods should be designed on the basis of empirical observations. All this represented quite a change from the prevailing management procedures at the turn of the century.

Taylor had given root to the idea that planning and doing ought to be separated. Consequently, planning staff specialists were required. Taylor also laid the foundation of literature concerning how things should be done. He also

demonstrated how to communicate the essence of these methods to be public at large. Finally, Taylor provided industry with the following principles of effective management: (1) develop a science for each element of an employee's work; (2) select and train employees scientifically; (3) establish firm cooperation with employees; (4) assume responsibility for the activities which are of a managerial nature.

Following Taylor, Frank Band Lillian Gilbreth were the first to put the motion pattern of the worker "under the microscope." In studying an operation such as bricklaying, they felt that there must be "one best way" to do a job. Their search for that one best way to do a job combined Frank Gilbreth's work in motion economy with Lillian Gilbreth's study of the psychological motivation of the employee. They concentrated on how the workers moved their body elements such as hands and arms and how long those elemental movements took. For example, close examination of bricklaying resulted in reducing the motions for laying each brick from 18 to 4.5 This reduction combined with other labor saving improvements led to an increase in a worker's bricklaying capacity from 120 to 350 bricks per hour.

The writings of Taylor and the Gilbreths are still timely. The work produced by these individuals led directly to the function of work measurements and methods engineering, the foundation of industrial engineering.

The growing interest in work measurements and methods engineering, facilities layout and design, and engineering economy and their effect on the production process led individuals to see the need of integrating all of these functions into operating systems. Individuals charged with these functions formed the American Institute of Industrial Engineers, Inc. in 1948. Their purpose was to develop a vehicle for communication of professional developments and to promote the advancement of what they now perceived as their profession, industrial engineering.

The communication of ideas through AIIE resulted in integrating newly developed techniques into the methods used to solve production problems. The mathematical advances in solving problems of resource allocation and product reliability were added to the industrial engineer's arsenal. Such expansion of functions available to the industrial engineer to meet challenges has continued through today. This same growth from the successful adoption of a single industrial engineering function through embracing the entire range of industrial engineering functions is a pattern typical of all firms, including those in shipbuilding. It is because of the success of firms which have followed and are following this historical pattern of evolution of industrial engineering that the consideration of the historical development of industrial engineering was an appropriate topic to consider at this briefing. The next portion of this briefing is a description of the principal functions of industrial engineering.

FUNCTIONS OF INDUSTRIAL
ENGINEERING

FUNCTIONS OF INDUSTRIAL ENGINEERING

Functions of Industrial Engineering

Industrial engineering is a collage of functions which relate to the design, improvement, and installation of integrated systems of people, materials, equipment, and energy. These functions are delineated separately because the industrial engineer identifies himself as a specialist in a particular function. For example, a firm will advertise for an industrial engineer who is a specialist in production and inventory control. The company expects to interview individuals who have gained and maintained expertise in this function through work experience and continued study. Further, the company should also expect that individual to be able to integrate and blend the other functions of industrial engineering into an effective operating production control system.

The industrial engineer is trained to work effectively to translate theory into practice. To develop a production control system the industrial engineer might first select a mathematical optimization model from the operations research function. That model would then be incorporated into a computer based simulation model of the production. The simulation model would then generate a series of feasible daily production requirements. Management would then decide which of those daily production schedules would be adopted. This example is typical of the industrial engineer’s use of many functions to develop a solution to a problem. The ability to move from theory to practice, from abstraction to reality is expected of the industrial engineer. It is also expected that the industrial engineer can implement technology through people to achieve improvements in productivity.

Figure 1 illustrates that industrial engineering functions naturally divide into two groupings, Systems and Technology, and Systems and the Human Element.

Technology functions are those which deal with systems and "things, " whether those "things" be computers, economic theories or facility layouts. The industrial engineering functions comprising this grouping are:

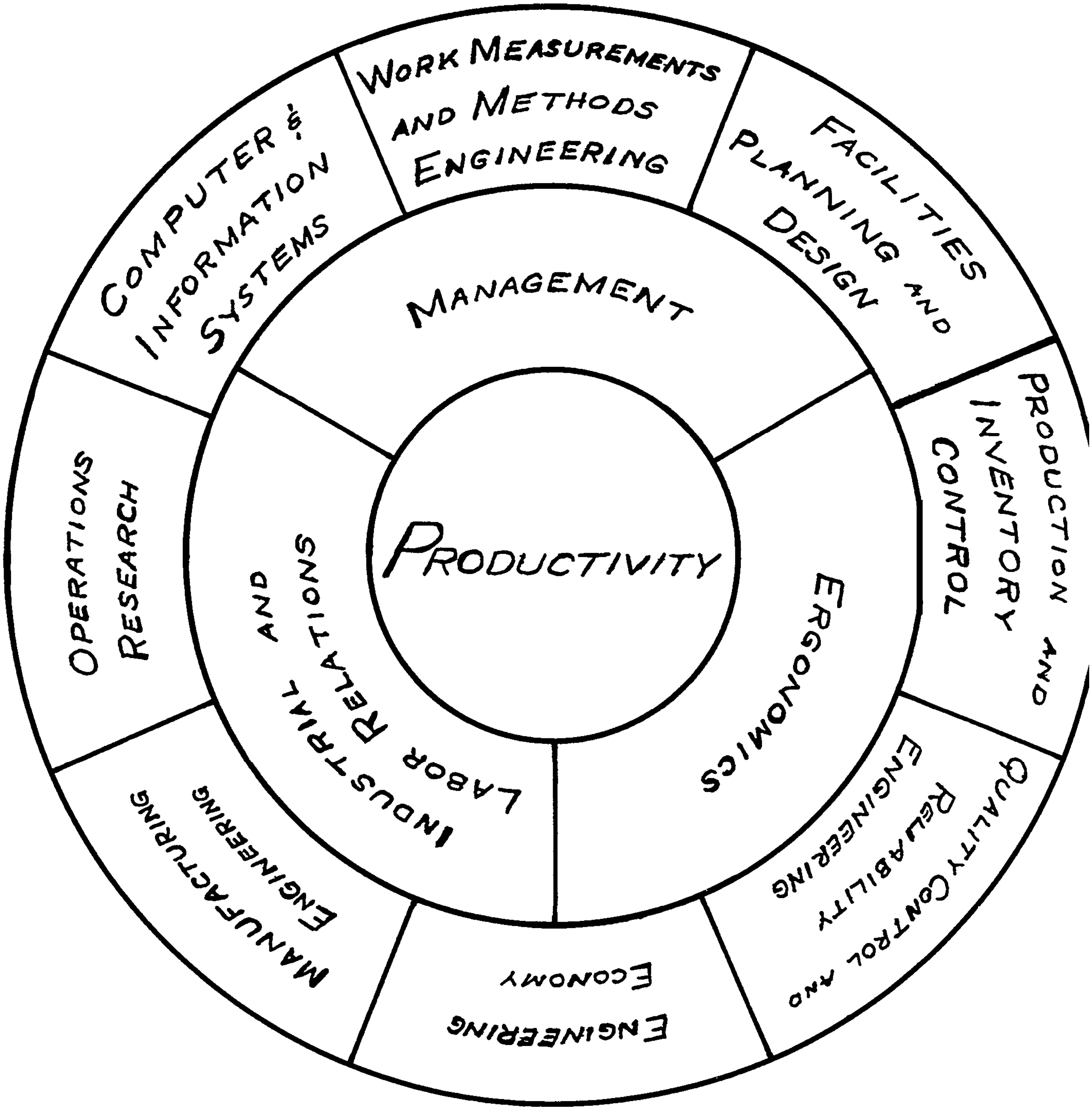
Work Measurements and Methods Engineering
Facilities Planning and Design
Production and Inventory Control
Quality Control/Assurance and Reliability Engineering
Engineering Economy
Manufacturing Systems
Operations Research
Computer and Information Systems

Figure 1 on the following page demonstrates the integration of industrial engineering functions. Mathematical optimization, macroeconomics, and computer technology would probably serve as the theoretical base. Production control technology would be used to develop a production scheduling model. The final results would be an on-line production scheduling program which would provide the lowest cost daily production schedule for work crews. By moving from mathematical theory to abstract production scheduling models to actual daily production schedules, the industrial engineer provides the link between theory and practice which integrates the appropriate functions into a working system. The outer ring of Figure 1 illustrates those functions used by the industrial engineer to meet the challenges found in industry and government.

Technology is necessary; however, it is people that make an operation successful. The industrial engineering functions relating to that human element are illustrated by the inner ring of functions in Figure 1. The functions are:

Ergonomics
Industrial and Labor Relations
Management

FIGURE 1: INDUSTRIAL ENGINEERING



"ON TARGET TO INCREASE PRODUCTIVITY"

It is the human element of the production system which accounts for the greatest source of variability. Consequently, it is this element which can result in the greatest gains or losses in productivity. As long as people are involved in the production process, people must be the concern of the industrial engineer. The industrial engineer must be able to relate the theory of human performance to the practice of production operations to achieve the targeted productivity improvements.

The industrial engineer uses technology through people to achieve productivity. The remaining portion of this section of this briefing will examine each of the functions of industrial engineering and discuss their possible payoff in the shipbuilding industry.

MANAGEMENT BRIEFING ON INDUSTRIAL ENGINEERING

FUNCTIONS OF INDUSTRIAL ENGINEERING

Work Measurements and Methods Engineering

Work measurements and methods engineering is devoted to the systematic study of work systems. The purpose of this function is fourfold: (1) to develop the preferred system or method to perform the work, where preference is measured by the method producing the lowest cost; (2) to standardize the system or method to produce reliable forecasts of future costs and a valid basis for cost control; (3) to determine the time required by a qualified and properly trained person, working at a normal pace to do a specific task or operation; and (4) to assist and train the worker in performing the specified task using the preferred method. When the preferred method is determined and standardized, those standards can be used to set prices, plan production, and estimate capacity and manpower. Consequently, work standards are the basis for laying out the entire production operation for a particular shipbuilding contract,

Work measurements and methods engineering techniques are necessary for managing todays complex manufacturing operations. The division of labor by craft and location requires detailed information on how a job will be done, and how long it should take to do that job. Work standards are not required to do a job. Work standards are only required if the objective is to do a job better, at a lower cost, reducing the risk of loss.

Appropriately, the establishment of work standards for shipyard production operations was one of the first activities sponsored by MarAd through their SP-8 effort. Work standards for selected shipyard operations in the six participating shipyards are being developed through the use of the H. B. Maynard & Co. MOST systern. Specific examples of the application of MOST in shipyards and the subsequent impact on costs will be provided later in this briefing.

The past decade has seen an increasing emphasis on work measurements and methods engineering in both service and manufacturing industries. Predetermined time standards are being adapted widely due to their increased flexibility over stopwatch studies. Currently, firms are computerizing their predetermined time standards to provide a comprehensive data base of task related information. This data base provides a tool to allow the industrial engineer to simulate manufacturing operations. The result of this simulation allows management to see in advance the effect on cost and time of changing methods or systems. After computer files of standard data are established by the industrial engineer, new standards may be developed by technicians responding to questions generated by the computer. This will free the industrial engineer to develop new methods, add new standard data to the data base and most importantly, gain acceptance of work measurement standards and methods by the employees.

More emphasis in the future will be placed upon applying job standards to a wider range of activities. Stress will be placed upon establishing consistent and accurate job standards to previously unstandardized functions. An example of this is the governmental insistence to implement Military Standard 1567. Job standards will be set for more clerical and white-collar tasks, as the cost of these tasks rise in proportion to direct labor costs of manufacturing.

The industrial engineer working with the work measurement and methods engineering function will also be faced with developing work methods which will be compatible with a younger labor force. It has been shown that this labor force does not subscribe to the “work ethic” to the extent of past generations. Consequently, human understanding and motivation must accompany work standards.

The industrial engineer is also cognizant of the need to consider the capacity of the worker to perform the job function in environments of stress, noise, vibra-

tion, and adverse climate conditions. Health and safety requirements constantly impact upon work methods and job standards.

The evolution of basic work measurement theory has been fairly well established. The principal work now being done in this function is toward applying these techniques to complex operations where standards have not been established. An example of such an activity would be establishing standards for particular tasks in shipboard outfitting.

Further, continued improvements in productivity are dependent on sound work simplification programs. Employees at all levels can contribute to properly managed work simplification. There is a high immediate payoff and a good long-term benefit. Often an employee suggestion of building a simple jig to simplify an awkward welding operation can result in significant savings.

Work measurements and methods engineering is the cornerstone of industrial engineering activities. These techniques provide the data for (1) preparing bids, (2) improving methods to increase productivity and lower costs, and (3) monitoring and controlling the production operations. The work measurement system drives the systems within the strategic plan. Ultimately, the long-range strategic plan is dependent upon whether or not the shipyard can standardize its work methods systems. As a critical element of the strategic plan as well as manufacturing operations, the impact of implementing the work measurement and methods engineering function on shipyard profitability would rate a three on a one to three scale. Consequently, involving the industrial engineer in this activity is a critical first step.

FUNCTIONS OF INDUSTRIAL ENGINEERING

Facilities Planning and Design

Shipyards must cope with producing a number of products with an uncertain ultimate demand over a long production lead time. Complicating the task even further is the increasing complexity of customer requirements and the increasing cost of materials handling. To attack these problems the industrial engineer initially separates the functions of facilities planning and design from those of materials handling. However, in developing the final solution to a problem these two functions are merged to obtain a sound operating system.

Facilities planning is the determination of how a shipyard's fixed assets should support the accomplishment of the firm's production and profit targets. The facilities planning function involves the arrangement of the yard, shops, drydocks, machines, and equipment to support production. This planning process must be continuous and ongoing. Today's facility alterations must be based on consideration of both current and future shipyard activities. Future changes will occur, so the facilities planner must be cognizant of the future. He must predict what effect today's alterations will have on tomorrow's requirements.

The industrial engineer engaged in facilities planning must recognize the best shop layout to sequence a deck module for a new contract. This layout must move the new deck module through the shop without adversely disrupting the production of existing deck modules. He should be able to answer the question of what layout modifications must be made in going from the construction of tankers to dry bulk carriers. He should also be able to determine when and in what sequence those modifications should be made.

The facilities planner must be involved in both facilities planning and layout design. Currently this mainly involves developing operations process charts

and flow process charts. These charts are the product of the engineer defining the problem, gathering and analyzing data and applying sound engineering judgment. Using these charts and “juggling” templates, a facility design evolves. This process depends upon a great deal of art and judgment based on experience. Because of the wide variation in judgmental solutions and the increasing complexity of production processes, current research is focusing on the development of computer-assisted design techniques and mathematical planning and layout models. However, the same complexity which has plagued the facilities planning and layout process to date has slowed the formulation of effective mathematical and computer models.

What is the payoff”for using industrial engineers in facilities design in shipyards? For shipyards with effective master plans for facility utilizations and with experienced layout staffs, the payoff is probably not as high as for other functions. The main contribution of the industrial engineer to facilities planning and design is in the overall understanding of the entire operating system.

Traditionally, industrial engineering efforts in materials handling have been focused on three basic areas:

1. Ways to reduce the distances travelled by materials.
2. More efficient equipment with which to move the materials.
3. Improved systems to manage the movement of materials.

This has brought the industrial engineer with materials handling responsibility into close contact with the facilities designer. Both sought to reduce material travel distance and to assure that facility design will take full advantage of new, efficient equipment designs. The industrial engineer has improved both the design and management of material handling systems. This improvement has been achieved through the appropriate application of mathematical and computer

simulation models combined with management information control. Queuing analysis and Monte Carlo simulation have reduced the cost of material handling while increasing system effectiveness. For example, a firm handling steel shapes was able to reduce the costs of a proposed material handling system by 23% ($3.2 million) through a computer simulation of material flow. This simulation showed that by careful material management, 23% of the proposed material handling equipment was unnecessary.

The most recent advances in material handling have come through the consideration of the characteristics of the materials themselves. These characteristics include size, shape, weight, risk of damage, condition, quantity, and timing. The aerospace industry has just completed a government sponsored study to classify sheet metal by characteristics in order to group materials into transportation classes. The anticipated savings in material handling is projected to be quite significant. Class grouping also provides the opportunity to simplify task analyses and identify those materials with high handling costs.

Given the variety of materials to be handled in shipbuilding, and the costs of that material handling, this is a function to which the industrial engineer can contribute to increase profitability. On a one to three scale, the payoff would rate as a two.

In summary, the industrial engineer can contribute significantly to solving materials handling problems. However, there would be probably only marginal return from immediate integration of industrial engineering into facilities planning and design.

FUNCTIONS OF INDUSTRIAL ENGINEERING

Production and Inventory Control

Production and inventory control techniques provide the means of controlling the resources used in the production process. This control system seeks to gain the maximum benefit for the shipyard at the lowest cost. Benefits would include meeting management objectives of quantity, quality, delivery time and profitability. The industrial engineer would (1) formulate mathematical models, (2) develop a production control system incorporating those models, and then (3) monitor the system, making adjustments as necessary.

The changes wrought by the industrial engineer in production and inventory control have been principally (a) the introduction of computer based production planning and inventory control systems, and (b) the incorporation of operations research techniques into the forecasting of product demand, the planning and scheduling of production, and the controlling of inventory levels. The analytical knowledge of the industrial engineer has allowed the development and implementation of new techniques within these systems.

Beyond analytical techniques the industrial engineer has introduced new computer based decision-making procedures into production control. These procedures rely on the ability to store vast amounts of operating data and manipulate these data through mathematical models to determine the optimal production and inventory control systems. The purpose of these systems would be to provide the desired shop floor control to achieve managements objectives. The systems would provide the basis for scheduling, dispatching and machine/crew assignment priorities.

For example, a typical problem facing shipyards might be the scheduling of work through the Pipe Shop. For each ship built, a complex set of piping must be fabricated through the cutting, bending, welding, and testing operations. The

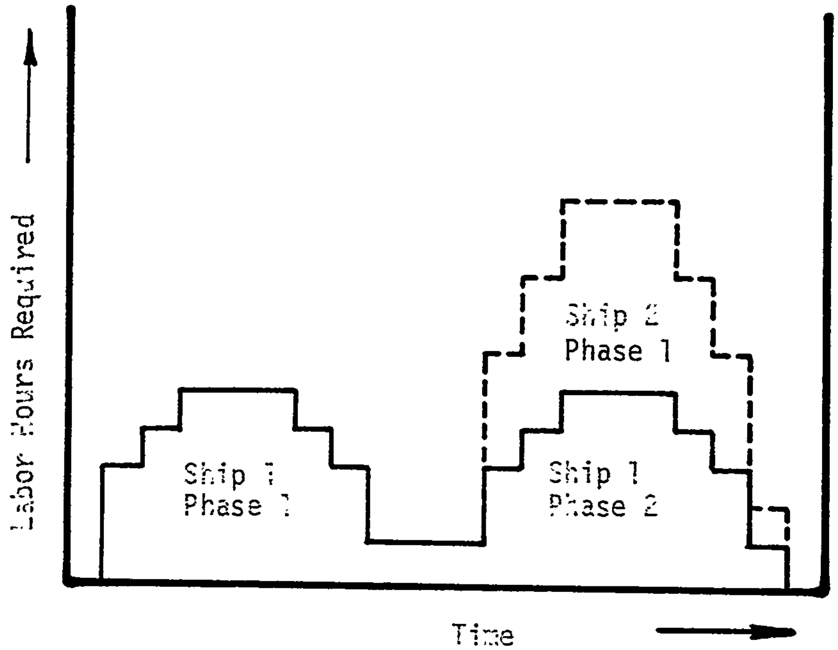
sequential flow of a production run of ships through the yard would result in a workload for the Pipe Shop of a series of peaks and valleys. Couple these fluctuating workloads with the additional disruptive effects of the demands of other ships, drilling rigs and the like. The result is a chaotic shift of work force demands from idle time to overtime. Such swings in demand disrupt the rhythm of the employees and are needlessly expensive.

Figure 1 illustrates the effect of scheduling variations of two ships on the Pipe Shop. Note that the first phase of piping construction of Ship 2 falls directly on top of the second phase of Ship 1. The result is predictable and undesirable. However, through proper planning, the first phase of Ship 2 can be moved forward to where it falls between phases 1 and 2 of Ship 1. This would level the workload for the Pipe Shop. This leveling effect is illustrated in Figure 2. While correcting such scheduling deficiencies may seem obvious, examples of such situations occur far too often in all industrial operations including shipbuilding. Proper analysis, planning and control of the production process avoids such situations.

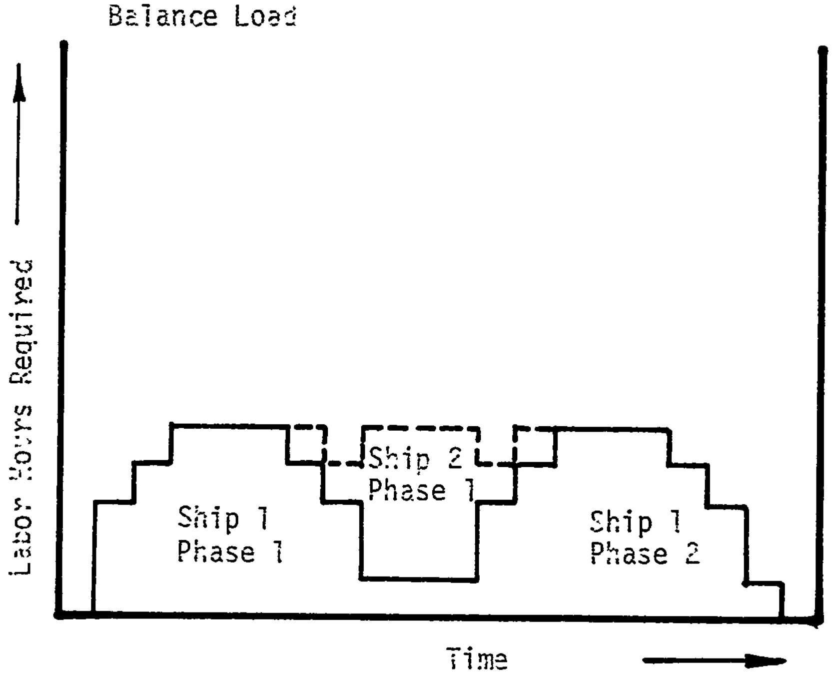
Production planning and inventory control has now developed to the stage where the analytical capability to solve problems exists. The computer capability is available to cope with the many variables and masses of data required to forecast, simulate, and monitor the production process. Consequently, production scheduling techniques such as Materials Requirements Planning (MRP) have taken on new importance. MRP allows the firm to have the right material at the right place at the right time. While this is a simple concept, it has only been adopted in the last few years. The savings from using MKP have been significant. The gap between theory and application in this function has become quite narrow. Consequently, significant advances in production and inventory control are being made in industry today. These advances are reinforced by the fact that firms are listening to the

Figure 1: Pipe Shop Schedule

Time Sequence



Balance Load



experienced employee who makes tangible suggestions for improvements. Those suggestions can be incorporated into the production scheduling simulation model and tested at a minimum cost. The ideas which would result in adequate cost savings can then be adopted.

The potential impact of an industrial engineering effort applied to production and inventory control is significant. Tying standard times and costs to the production scheduling process is probably the second critical step in implementing industrial engineering. The first step would have to be the development of those work standards. On a one to three scale, again this industrial engineering function would rate a three in potential payoff and profitability.

MANAGEMENT BRIEFING ON INDUSTRIAL ENGINEERING

FUNCTIONS OF INDUSTRIAL ENGINEERING

Quality Control/Assurance and Reliability Engineering

"Quality has much in common with sex. Everyone is for it (under certain conditions, of course). Everyone feels they understand it (even though they wouldn't want to explain it). Everyone thinks execution is only a matter of following natural inclinations. And, of course, most people feel that all problems are caused by other people." (Phillip B. Crosby) Quality control is not simply a function limited to the realm of industrial engineering. Probably more than any other function of the systems and technology group, the success of quality control/assurance activities depends upon the joint effort between the industrial engineer and management. No program of quality control will be worthwhile unless shipyards discard any remaining mistaken assumptions and misguided policies which generate problems rather than solving them. If the entire organization strives to achieve the desired attitude toward quality, the benefits will be truly significant. "Quality is not only right, it is free. And it is not only free, it is the most profitable product line we have." (Harold S. Geneen)

Considering the cost of rework, testing, inspections, servicing, and scrap, to say nothing of customer dissatisfaction resulting in lost future business, shipyards cannot afford not to be quality conscious.

Quality is conformance to requirements. Quality is not just "goodness" and error is not inevitable. Quality must be designed into a product, manufactured into a product, and must be retained in the product throughout its life. Blaming our workers for poor quality is a management escape hatch. Experts have shown in numerous studies that at least 80% of all defects are problems that only management can do something about. Workers

and management alike can ill afford to have a dual standard of quality: one for their personal lives, another for their work hours.

Specification of an acceptable quality level (AQL) assumes implicitly that mistakes will occur. Certainly, errors arise in an operation. Variability in manufacturing operations is an expected and natural phenomenon. However, the way to assure quality is to make certain that all levels of the shipyard, workers through management, are committed to quality through the elimination of the source of errors.

The industrial engineer can provide strong support to a quality assurance program. By the knowledge gained through training and experience, the industrial engineer can develop and apply the technology while understanding and motivating the employees to take the steps necessary to make sure that perfection is a realistic expectation.

Total quality control must encompass the entire product spectrum from the designer through the customer. To monitor and improve the quality assurance system the industrial engineer must be cognizant of statistics, materials, manufacturing systems, and how to properly weigh cost-effectiveness trade-offs. The industrial engineer must also understand the human element. He must know how to effectively motivate employees toward zero defects. He must understand how to implement techniques such as “quality circles.” The total quality requirement requires the knowledge of the industrial engineer in (1) working with management on establishing a policy for determining the market level of quality, (2) working with the designer to develop a product which will achieve those levels of quality, (3) coordinating the control over receiving to insure starting with quality raw materials and purchased parts, production, to maintain quality level during manufacture and inspection and testing, to insure adherence to design specifications, and (4) monitoring

field trials and customer usage to insure that quality levels are appropriate and product effectiveness is maintained.

The industrial engineer is well trained in statistics and understands the techniques of control charts, acceptance sampling, reliability and maintainability. He is also trained in the psychological and physiological limitations of the human in the manufacturing task. Consequently, he can work with the techniques encountered in traditional quality control systems. The challenge that must be met by the industrial engineer is that posed previously. The industrial engineer must work with all levels of management to motivate both workers and managers to achieve perfection. For this reason the application of this function varies from the others described in this briefing.

If management is committed to a total quality assurance program, then the impact on profitability of the quality control/assurance and reliability engineering could rate a three on a one to three scale. Without such a commitment, the impact would be a one at best.

MANAGEMENT BRIEFING ON INDUSTRIAL ENGINEERING

FUNCTIONS OF INDUSTRIAL ENGINEERING

Engineering Economy

Engineering Economy is a function concerned with capital budgeting. It principally deals with the analysis of the feasibility of the capital expenditures making up that budget. A capital expenditure opportunity entails a cash outlay with the expectation of future benefits over one or more years. These expenditures include machinery, equipment and buildings, as well as less tangible expenditures for research and promotion. The analysis of the feasibility of these expenditures requires the industrial engineer to estimate the future costs and benefits of the proposed expenditure through forecasts and predictions. Future uncertainties dictate that the engineer consider a set of alternative capital expenditures so that the best solution to the problem can be discovered and implemented.

To determine the worth of any alternative capital expenditure, four variables must be defined: (a) all relevant costs and the point in time when these expenditures occur; (b) all benefits and revenues attributable to those expenditures and the point in time when they occur; (c) the economic life of the alternative; and (d) the interest rate which relates the time at which costs and revenues accrue and which accommodates the risk of the uncertain future. It is this estimation of costs, benefits, times and uncertainties concerning proposed capital expenditures which requires experienced engineering judgment.

Using the estimates of costs, benefits, economic life, and interest rates associated with economic alternatives, these alternatives would be compared using the techniques of annual cost, present worth, and rate of return. This comparison would include the impact of tax effects as well as non-monetary factors such as

legal, political, esthetic, and security factors. Typical comparisons would include analyses (1) between two competing methods of doing the same job, (2) of whether *or* not a particular project or piece of equipment is economically justified, and (3) of whether or not to replace an existing capital asset with a new asset or "challenger."

A typical analysis performed using the techniques found in the industrial engineering function of engineering economy would be to determine whether fuel or electric fork lift trucks would be the most economical choice to replace aging units now in service. Further, the analysis would address when such a replacement should occur and whether the units should be bought or leased. Likewise, the industrial engineer would be expected to understand the significant financial impact on an analysis from depreciation between storage facilities installed within a building and a storage facility constructed so that the building only served to "cover and brace" the materials handling equipment.

Considering the probabilistic outcomes of uncertain future events, the industrial engineer was able to consider the possible alternative outcomes of a particular investment or event. Estimating the probability of each outcome provided a means of determining the expected value of that expenditure. These techniques led to the development of decision trees. The decision trees allowed the consideration of the consequences of a series of outcomes over time.

Returning to the problem of analyzing the fork lift trucks, the decision of whether to buy truck A or B could be formulated as a decision tree. In examining the life cycle cost of these units the industrial engineer would consider the initial cost of the units as well as the maintenance cost over the life of the equipment. Assume that the firm also wished to renovate or renovate and expand its maintenance facility. This decision would depend upon

the amount of maintenance work to be generated by the fork lift trucks. Consequently, the first year's maintenance would dictate whether to expand or renovate. The alternatives are illustrated in Figure 1.

Another technique using probabilistic outcomes is the payoff matrix. This technique was used recently by a defense contractor to analyze alternative bidding strategies. The analysis incorporated considerations on how much to spend on capital equipment to enhance the chance of being awarded the contract, how much capacity was available for existing possible future contracts, how additional capacity could be obtained (overtime vs. subcontractor) and finally which contracts to bid on. The payoff matrix, illustrated in Figure 2, allows strategic analysis at a single point in time.

While these probabilistic techniques were being introduced into the engineering economy function, a new awareness was being manifested toward the impact of capital expenditures on the financial structure of the firm. This led to multi-criterion decision models which could weigh economic impact on criteria such as sales growth, return on assets, and market share.

The use of industrial engineers in the engineering economy function varies as widely in all industries as it does in shipbuilding. For the firms not using discounted cash flow techniques, the impact of introducing industrial engineers into the capital expenditure analysis process could be as great as a three on a one to three scale. If, however, discounted cash flow techniques are already in use, probably little impact would be noted. The impact rating would be a one in this case. Finally, if the industrial engineer is brought into the strategic planning process, there is the opportunity of a significant impact. This impact would occur through integrating the functions of engineering economy with operations research, computer systems and management for a three rating. Such a prediction is, of course, predicated on the existence of a standard methods and costs system.

Engineering Economy: Decision Trees

Two vehicles have been qualified as potential replacements for your fork lift truck fleet. Supplier A will provide the needed units at a cost of $600,000. Supplier B will charge $450,000, but its units may require more maintenance and repair than those from Supplier A. To stretch the life of either brand of vehicles you are considering modernizing your maintenance and repair facility either by renovation or renovation and expansion. Although expansion is generally more expensive than renovation alone, it enables greater efficiency of repair and therefore reduces the annual operating cost of the facility and reduces the cost of unit downtime. The estimated cost of renovation alone and renovation and expansion, as well as the ensuing operating costs depend upon the quality of units purchased and the extent of the maintenance they require. Management has agreed with your proposed strategy: purchase the units new; observe their maintenance requirements for one year; then make the decision as to whether to renovate or to renovate and expand. During the one-year observation period, you will get additional information about expected maintenance requirements during years 2 through 5.

If the units are purchased from Supplier A, you have estimated first year maintenance costs to be low ($20,000) with a probability of 0.6 or moderate ($30,000) with a probability of 0.4. If they are purchased from Supplier B, maintenance costs will be low ($20,000) with a probability of 0.3, moderate ($30,000) with a probability of 0.6, or high ($40,000) with a probability of 0.1. The costs of renovation (NPV), shown below, depend upon the first year's maintenance experience.

One-year maintenance requirements	Renovation costs	Renovation and Expansion Costs
Low	$100,000	$200,000
Moderate	150,000	300,000
High	200,000	400,000

Expected maintenance cost for years 2 through 5 can best be estimated after observing the maintenance requirements for the first year.

Maintenance Costs for Years 2 through 5 (NPV)

		Renovate		Renovate and Expand	
Supplier	First Year Maintenance	Maintenance Years 2 through 5		Maintenance Years 2 through 5	
A		Low	Moderate	Low	Moderate
	Low	$100,000	$150,000	$40,000	$60,000
	Moderate	100,000	150,000	40,000	60,000
B		Moderate	High	Moderate	High
	Low	$150,000	$200,000	$50,000	$90,000
	Moderate	150,000	200,000	50,000	90,000
	High	250,000	300,000	70,000	100,000

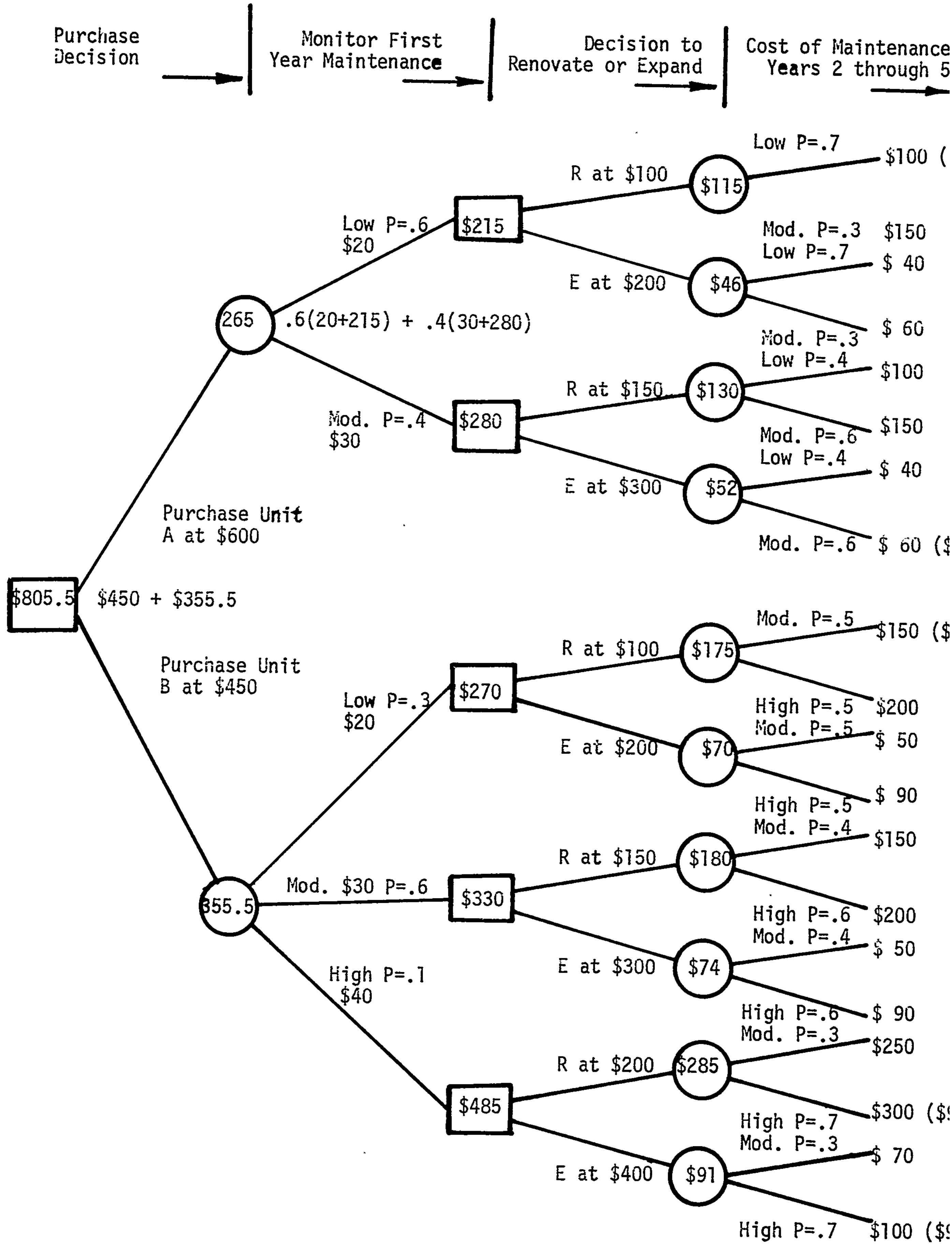
Probabilities of various maintenance levels in years 2 through 5 depend upon the types of units selected and the maintenance experience during year 1:

Probabilities of Maintenance Effort, Years 2 through 5

Supplier	First Year Maintenance	Maintenance Level Years 2-5		
		Low	Moderate	High
A	Low	0.7	0.3	.
	Moderate	0.4	0.6	--
B	Low	--	0.5	0.5
	Moderate	--	0.4	0.6
	High	--	0.3	0.7

Developing the 5 year strategy that will minimize expected costs, the decision tree on the following page illustrates all of the possible alternative outcomes. To minimize expected costs, purchase the fork lift trucks from Supplier B. Plan to renovate and expand the maintenance facility if the first year's maintenance is low, or renovate only if the first year's maintenance is moderate or high. While this recommendation is based on expected values, note that the maximum cost exposure for either A or B is $990,000 while the minimum possible cost is $720,000 for fork lift trucks from Supplier B as opposed to $820,000 for those from Supplier A.

Figure 1: Decision Tree Solution



MANAGEMENT BRIEFING ON INDUSTRIAL ENGINEERING

FUNCTIONS OF INDUSTRIAL ENGINEERING

Operations Research

Operations Research has never been succinctly defined. This function is usually described as the application of the scientific method to solving problems found in operating organizations. The process of operations research begins by observing and defining the problem. A model is then constructed (typically a mathematical model) that attempts to abstract the essence of the problem. After determining that the model is sufficiently precise to represent the operation under study, a solution is obtained for management’s evaluation and implementation.

Operations Research had its inception in England during World War II. A team of scientists was called together to use their scientific expertise to determine the most effective way to utilize the country’s limited resources to aid the war effort. Strategies developed by these teams were instrumental in the success of the “Air Battle of Britain” and the “Island Campaign in the Pacific.” The industrial development following World War II experienced problems caused by the increasing complexity and specialization in organizations. The efforts made to solve those problems resulted in the growth of operations research in American industry.

The function of operations research in industry owes much of its initial impetus to the successes achieved in using the simplex method for solving linear programming problems. The simplex method was developed by George Dantzig in 1947. It achieved significant savings in solving problems of blending (petroleum refining, metal alloys) and scheduling work crews. A simplex model was also used to rate prospective football players by the Dallas Cowboys (cheerleader

evaluation is still strictly subjective).

Operations Research techniques have been used by the industrial engineer to solve a number of industrial problems. Techniques finding a high rate of successful application are statistical techniques such as forecasting and regression analysis; linear programming; and simulation. Statistical techniques are incorporated into the quality control/assurance function, inventory control, and production planning. Linear programming has been used to find optimal production schedules, inventory policies, plant locations and layouts, and labor assignment policies. Simulation has provided alternative solutions for management evaluation in problems of preventive maintenance scheduling, production planning and scheduling, inventory control, plant layout, and capital equipment acquisition and replacement. Network techniques have been used less in industry than these other operations research techniques. Network analysis has been applied to project management (PERT/CPM) and some production scheduling and routing problems.

The main difficulty in successfully applying these techniques is in the lack of data required for formulating and solving the mathematical models. It is usually necessary to have good work and cost standards, an effective part numbering system and established production procedures. Without adequate valid data, any answers derived from mathematical models are suspect.

A recent application of operations research study techniques by an industrial engineer to shipbuilding involved the preparation of supporting analysis for an appeal of the Ingalls Shipbuilding Division of Litton Industries before the Armed Services Board of Contract Appeals (<u>Interfaces</u>, Vol. 10, No. 1, pp. 1-11). This case involved a Litton claim that it should be compensated for the additional costs incurred in fulfilling its submarine contract because of extensive design changes resulting from the "Thresher" accident. These design changes not only

created costly schedule disruptions of the submarine program, but also disrupted the construction schedules of five surface vessels for the Navy and fourteen vessels for three commercial concerns. The question was whether or not a causal link existed between the forced rescheduling of the nuclear submarine program and the subsequent decline in efficiencies elsewhere in the shipyard. Statistical pattern analysis was used to show that the likelihood that the efficiency drop in the commercial program was due to random variations was less than one change in a trillion. While this study comprised only a small partion of the testimony heard in the appeal, it did provide objective reinforcement of the opinions and observations of shipyard personnel. The payment to Litton by the Navy to satisfy the formal decision of the Board amounted to approximately $51 million. Certainly this example could be considered a non-traditional application of the operations research function to shipbuilding. However, this example does demonstrate that the application of mathematical models through the scientific method can have a positive payoff.

Other operations research techniques are potentially useful in shipbuilding. Network analysis techniques could be used to analyze the problems of pre-outfitting, as is being investigated under a current research contract. This research is attempting to determine the feasible degree of pre-outfitting. The research will consider what tasks should be included in the pre-outfitting and when these tasks should be done. The decisions on task inclusion would be based on cost minimization with an eye toward the maximum unit load which could be handled with existing equipment.

The contributions of the operations research function to solving problems faced by operating organizations have been: (1) to structure real life situations into mathematical models, abstracting the essence of the problem for specific analysis; (2) to explore the structure of potential solutions and develop

systematic procedures to obtain potential solutions; and (3) to develop solutions yielding optimal values of costs or profits.

Operations Research has the potential to contribute to management's profitability objectives in shipbuilding. The potential impact would probably be two on a one to three scale. However, to achieve this impact it would probably be necessary to implement other industrial functions such as work measurements and methods engineering prior to fully realizing the impact of operations research.

MANAGEMENT BRIEFING ON INDUSTRIAL ENGINEERING

FUNCTIONS OF INDUSTRIAL ENGINEERING

Manufacturing Systems

Manufacturing systems encompasses the design of the product and the design of the system to produce that product. To effectively work in the manufacturing systems function, the industrial engineer must understand techniques such as forming, holding tolerances, assembling finished goods, processing times, and finishing requirements. He should understand the productivity improvements possible through automation. He should have the facility to evaluate the cost trade-offs involved in automating a process. He must also recognize how and when to substitute a device for human effort and how to control that device.

Since a manufacturing system is also composed of people, the industrial engineer must be aware of the psychological and physiological functions of the operator which will contribute to the success or failure of a system. It is the blending of the functions of industrial engineering to increase the productivity of manufacturing systems that is the objective of this function.

The industrial engineer devoted to the function of manufacturing systems is the person who plans, develops, and optimizes the processes of production. His duties involve the methods of manufacturing and designing tools and equipment for manufacturing in addition to administrative and supervisory responsibilities.

The working environment of the industrial engineer in manufacturing systems responds to technological advance and social pressure. Areas of special concern to the manufacturing systems function were noted in a recent report by Batelle/Columbus Laboratories. These concerns were (1) the energy shortage, (2) the social changes of the past decade, (3) the lagging industrial

productivity, and (4) the computer-oriented accomplishments of the past fifteen years.

The highest level of automation in manufacturing systems is computer integrated manufacturing. Computers are used to coordinate and optimize all phases of manufacturing. When fully implemented the result is the automated factory such as is now found in Japan. While many experts expect this type of factory to be much more common in the next fifteen years, it is unlikely that shipyards would be so highly automated due to low production runs and the size of the product produced.

Currently, manufacturing systems are designed to take full advantage of numerically controlled machine tools used in concert with computer-controlled materials handling systems. Parts to be machined are sorted and coded into families suitable for automatic processing. These system developments are made possible through innovation in the elements of the system. These elements include machining centers, computer-aided operations, minicomputers, micro-computers, adaptive controls, automated diagnostics and microprocessors. The industrial engineer working in the manufacturing systems function is actively involved in developing these elements and adapting them to manufacturing systems.

Group technology is the organizing and planning of the production of parts into batches that exhibit some similarity of geometry or processing sequence. Group technology is a small batch technique, so it has promise for wider adaptation in shipbuilding. This technology brings significant increases in efficiency and productivity to the production process. However, the use of group technology requires resequencing and reorganizing the production process. This reorganization of the production process is one of the challenges now facing the industrial engineer.

The Battelle report also noted trends in advances being made in designing tools and systems. Lasers and electron beam applications to cutting, welding and metal hardening are expected to increase 50% in the next five years. Industrial robots for riveting, welding, and painting will see greater use in manufacturing systems and should impact shipyard operations. Major advances should also be expected in machine tool control, machining accuracy, surface finish, structural stiffness and noise characteristics. Flexible systems involving several machine tools acting in concert, directed through computer control, will become commonplace.

The technical advances in the manufacturing systems function dictate that the industrial engineer work closely with other industrial engineering functions such as computer and information systems, facilities planning and design, and production planning and control. Furthermore, the rapid advances in technology require a new appreciation of the short economic life of equipment in such an environment. It will be necessary to shorten payback periods through shrewd selection of system elements and through astute efforts towards optimizing the manufacturing process.

Because of the importance of manufacturing systems in shipbuilding, the role of the industrial engineer is critical. New technologies are changing manufacturing operations. New production systems must be developed, discarding the "tried and true," to take full advantage of these new technologies. For shipbuilding, the impact of the industrial engineer in the shipyard actually working on developing new technologies would probably rate a score of one. However, the impact of the industrial engineer working on better procedures to take advantage of new technologies to increase productivity would rate a three on the one to three scale.

MANAGEMENT BRIEFING ON INDUSTRIAL ENGINEERING

FUNCTIONS OF INDUSTRIAL ENGINEERING

Computer and Information Systems

The computer and information systems function of industrial engineering diverges into two major classes of activities. The first major class of activities concentrates on the study of computers and information systems for their own sake. The second focuses upon the integration of computer and information systems into the other functions of industrial engineering to solve problems encountered in operating systems. Because the orientation of this briefing towards the application of industrial engineering to solve problems in shipyards, only the second class of activities will be considered.

A management information system is a communication system which collects and processes data to produce information to support the management of an organization. The term "processing data" includes the activities of recording, storing, calculating statistics and retrieving data. Management information is the driving force which welds together all the functions of the firm. Information is one of the firm's greatest resources and is the manager's source of power and his base for effective operations.

While the industrial engineer is often assigned to work with the firm's overall management information system, the industrial engineer's principal assignments emphasize the production information system. Just as information is the driving force of the firm, production information is the driving force of the production system. Information is critical to today's complex production system. No one individual can monitor and control all of the activities of the production system through observation and intuitive judgment. Consequently, the industrial engineer seeks to automate the operation of the production system.

It is possible to automate whatever can be exactly specified. Most ostensibly human prerogatives for inferential, judgmental, learned and adaptive behavior can be exactly specified with respect to finite contexts. Thus, within specified frameworks much ostensibly intuitional and creative human behavior can be indistinguishably imitated by machine. This means that a production system can be designed and then innervated with appropriate data streams.

Information to operate the production system is not free. The costs of processing production data typically will run between 5% and 15% of the cost of the production operation. While the costs of providing information are tangible and measurable, the value of information is often elusive. The value of the information provided to and obtained from the production system must be weighed against the costs of obtaining and processing these data. The industrial engineer can draw upon the techniques of the engineering economy function to determine these cost-benefit relationships.

After the industrial engineer has obtained the necessary production data base, it is then possible to utilize the techniques from other functions of industrial engineering. These techniques would be used to manipulate those data to achieve management’s objectives.

For example, using a computerized work measurement and methods engineering data base, it is possible to synthesize the elements of a task and determine the best method for performing that task. Combining the work measurement data base with a proposed production plan, it is possible to test the feasibility of that production plan. This test would vary the levels of output demand, labor loadings, machine scheduling, routines and the like. The result of the test would determine how sensitive the effectiveness of that production plan would be to changes in any one variable or a combination of several

variables. This representation of the characteristics of the system by operations performed by the computer is known as “simulation.” Simulation is used not only in production and inventory control, but in many other industrial engineering functions. For example, one could use simulation to test various capital budgeting alternatives. Simulation is most useful where it was not possible **to** find exact solutions to a problem.

Other industrial engineering accomplishments have been possible only because of the availability of economic computer resources. Material Requirements Planning (MRP) was implemented only after economic computing capability became available because MRP requires that the firm keep track of an enormous number of items. The industrial engineer can also develop operating models which allow management to ask “if-then” questions. These questions **test** the possible consequence of a proposed action inexpensively, well in advance of any implementation.

These modeling and simulation techniques would not be possible without the computer. Consequently, a number of industrial engineers have chosen to become involved with computer hardware. Their main objective is to determine how one might use that hardware to support industrial engineering functions. One of the most active areas in adapting computer hardware is found in the manufacturing systems function. In this function the industrial engineer adapts microprocessors to control the manufacturing process. Again, the industrial engineer is taking a leading role in applying theory, techniques and devices from other disciplines to meet assigned challenges.

The effective impact of this function of industrial engineering is dependent upon the effectiveness of management’s acceptance and use of the computer. The computer is effective if it is used to “make chips”; that is, if it is directly related to the production of goods and services. The

industrial engineer views the computer and its programs as a production tool, not just a contribution to overhead. Used effectively, this function rates a three in potential impact on a one to three scale.

Much of the success achieved through the functions of industrial engineering has been dependent upon the effectiveness of the human user. The next section of this briefing will consider the industrial engineering functions which deal with the human element of the organization.

MANAGEMENT BRIEFING ON INDUSTRIAL ENGINEERING

FUNCTIONS OF INDUSTRIAL ENGINEERING

Ergonomics

Ergonomics comes from the Greek word expressing the relationship between man and his work. The objective of ergonomics is to achieve the optimum output in performance when considering efficiency, human capability, safety and health. This is the newest function incorporated into industrial engineering. Ergonomics has encompassed the study of the physiology and the psychology of the worker, the equipment and tools used by that worker, and the environment in which the work is performed. The design of the machines, work tasks, and work environments must match human capabilities and limitations. It is evident that this industrial engineering function operates closely with the industrial engineers concerned with work measurements and methods engineering.

The increasing concern for productivity, occupational health and safety, product safety and equal employment opportunity has emphasized the need for industrial engineers to be cognizant of ergonomic design principles. For example, how does a shipyard determine and defend whether a particular job involving lifting can be performed by males or females? Ergonomics research has provided data accepted by NIOSH which relates the maximum acceptable weight of lift predicted for classes of lifting ranges for each percentage of the male population. It was found that females could handle approximately 60% of the weight for each category. These data, when coupled with information on job severity, provide a means for screening employees for manual handling tasks and also indicate which lifting tasks should be modified to reduce worker injury. Ergonomic research has also provided data on the variability of human body size, arm-leg reach, and human muscular strength. These data would be used to better understand man's working capability.

Historically, the emphasis on productivity has focused on time and motion economy to provide a framework for breaking jobs into elemental tasks. Accumulating these tasks provided a prediction of job time requirements. These data serve as a measure of the physiological limits to the time required to complete a motion. Ergonomics has now examined the limits to human force or torque (strength) producing capability. For example, the magnitude, direction, frequency and duration of movements of loads would be used to design work methods for manual materials handling in ship outfitting. The escalating costs associated with manual materials handling and its concomitant hazards have forced a more careful examination of the underlying causes of mismatching jobs and workers. Handling and hazard costs justify better screening of employees using data from ergonomic studies. Greatly aiding this effort is information from (1) biomechanical analyses of strength tests, (2) biomechanical analyses of the job requirements for physical strength and reach requirements, and (3) metabolic analysis of whole body endurance.

Assuming that the operating capacities of the machine or system are comparable with the capabilities of the human operator, what other problems might arise? How does noise effect health? How does noise effect productivity? The operation could show deteriorated productivity long before adverse health consequences were noted. Another situation arises where equipment to protect the worker has significantly deteriorated productivity without conclusive evidence that such protective equipment is necessary. The passage of the Occupational Safety and Health Act in 1970 has put new urgencies on these problems.

Ergonomics has provided research to solve the problems found at the man-machine interface. This research is problem oriented and has quickly been translated into problem solutions. In these research efforts, industrial

engineers monitor:

1. Human operating characteristics;
2. Man-machine relationships including studies of control display and information flow;
3. Environmental conditions of heat, light, noise, vibration, fumes, and so forth;
4. Work aspects including human capacity fatigue, stress, errors and accidents, safety and system effectiveness.

The impact of industrial engineering involvement in ergonomics is elusive, for that involvement is generally mandated by law or administrative dictate. However, firms with industrial engineering departments active in the ergonomics function have achieved excellent results. Industrial experience has shown the impact varying from a three to one on a three to one scale. Heavy industries, which would seem to be the greatest benefactors have been the least active in the ergonomics function.

MANAGEMENT BRIEFING ON INDUSTRIAL ENGINEERING

FUNCTION OF INDUSTRIAL ENGINEERING

Industrial and Labor Relations

Industrial relations are the relations of persons and groups growing out of employment in the production of goods and the provision of services. Labor relations applies to the negotiation and administration of group relationships, where those groups are usually organized labor unions. While these formal definitions spell out the role and scope of the industrial engineer's activity within the function of industrial and labor relations, the reality is that ultimately the engineer must deal with problems that concern the employees. Whether those problems concern individuals or groups, "people" problems are among the most challenging ones encountered by the industrial engineer. There is variation in these problems resulting from the underlying variations in the people themselves. The organizational hierarchy in which people operate produces variation. The final source of variation is the perceived purpose of the organization. These variations tend to render handbooks, formulas and the like Wanting as tools for solving people problems. The problems faced by the industrial engineer are people to people problems. When these problems are described with labels like "labor-management," or when we say that "management wants to reduce the cost of employee absenteeism," we seem to imply abstract entities without flesh and bone.

It is people who make judgments about other people. The more equitable those judgments, and the more those judgments are based on sound data, the more effective the organization becomes. Discussions over issues touch emotional considerations such as compensation, work conditions, job security, and discrimination. These considerations involve the concepts of equity, justice

and fairness.

The industrial engineer is in a position to greatly influence human relationships. Setting fair work standards, establishing equitable working conditions, designing fair requirements for work stations, maintaining just job evaluation plans, understanding social relationships and problems of workers in establishing work schedules in production control plans and in facility layouts are the challenge to the industrial engineer. The development and implementation of quantitative methods and improved systems cannot ignore the impact all employees have on the success of these systems. The introduction of new manufacturing systems technologies of tools and equipment cannot neglect the patience and understanding required in educating and training the employees that will use that equipment. Consequently, the industrial engineer has the ability to create an atmosphere of either dynamic tranquility or disruptive conflict.

Industrial engineers become involved in the industrial and labor relations function either directly or indirectly, through most of their activities. For example, one of the general requirements of a quality circle program is to have an individual trained in industrial relations as a member of each circle. In many firms the industrial engineer performs this role. The industrial engineer also provides production and work standards. He should be closely involved in the industrial relations process as long as collective bargaining governs the workplace. He can assist in resolving differences or opinions, including grievances over work standards. The practice of industrial engineering does involve the “wages, hours and conditions of employment of both white and blue collar workers.” Further, the knowledge of the industrial engineer in fitting the job to the man through the previously discussed ergonomics function will assist in relating the growing body of legal requirements and

administrative rulings to labor contract negotiations. Knowledge of labor contracts will provide necessary constraints to models used in planning manpower requirements and production schedules. Finally, those models can be used to simulate the effects of altering contract clauses on production schedules and firm profitability.

For example if an industrial engineering related grievance goes to arbitration, the industrial engineer should share in the preparation and presentation of the case and the selection of the arbitrator. Because of the varying degrees of technical sophistication of the arbitrators, the case should be prepared from “ground zero” as far as the explanation is concerned. It is necessary to find out what the situation in the shop actually was at the time of the grievance, not what someone said it was. What methods were actually used or what conditions actually existed? Was there an accepted shop floor practice that was never acknowledged by the front office? A thorough analysis must be made of both sides of the situation so that the strongest possible case may be developed. A strong case is necessary for equity, for arbitration is seeking a fair decision. The role of the industrial engineer is important in developing a proper grievance case.

The role of the industrial engineer in industrial and labor relations is necessary for effective system operation. However, it is usually an indirect role, providing vital information and coordination, rather than having line responsibility as in other industrial engineering functions. Consequently, the impact of this industrial engineering function on the firm would probably rate as a two on a one to three scale.

MANAGEMENT BRIEFING ON INDUSTRIAL ENGINEERING

FUNCTIONS OF INDUSTRIAL ENGINEERING

Management

Management is the most human oriented function of industrial engineering. Management is the function of getting things done through others. A manager must (1) set forth his objectives and plan his work to meet them, (2) organize the factors of production, (3) secure qualified personnel to do the work, (4) direct the efforts of his employees, and (5) control the activities of his subordinates. These functions are usually restated as planning, organizing, staffing, directing, and controlling. Management is both an art and a science. It is an art, for it deals with the application of knowledge and skill in achieving a desired result. It is a science because it is concerned with knowledge obtained by study and practice.

The industrial engineer is involved in management in both line and staff positions. Further, he is involved at the macro level of the overall corporate structure and at the micro level of the industrial engineering department. At the corporate level the industrial engineer must first and foremost understand management's objectives. Secondly, he must work effectively with management to accomplish those objectives. At the departmental level, the industrial engineer must manage the industrial engineering function so that it will effectively serve management and increase corporate productivity. Productivity improvement will occur through the applications of industrial engineering techniques through the firm's employees. This effort in productivity improvement is the culmination of the industrial engineer's training and experience.

As Peter Drucker has noted, "The effective executive does not make many decisions. He solves generic problems through policy." It is the task of the industrial engineer to provide the data on which to build those policies

for the production operation and to provide the systems through which those solutions can be implemented. He is in a unique position to accomplish this because of his unique understanding of the many facets of the production operation.

Unfortunately, many people confuse bad management with destiny. Much of this attitude is generated by the neglect of the management function. The only things that evolve by themselves are disorder, friction and malperformance. Good management is achieved through sound planning and hard work. Management goals are achieved through consciously striving to reach objectives, not through periodic monitoring of exceptions. An individual in a managerial role must exert maximum effort to accomplish the sought-for objectives. This means that all departments must be cognizant of those objectives and skillful and creative in their achievement. Management by objectives works if you know the objectives. Unfortunately, ninety per cent of the time you don't.

When the objectives of the firm are clear, the next task is to accomplish those objectives. Much has been made in recent years of the success of Japanese shipyards in increasing productivity. Studies have shown that in most instances Japanese technology is not superior to that found in the United States. Further the Japanese worker is no more skillful than the American worker. However, the management style of the Japanese firm differs from the style of the American firm, and this style differential is credited for much of the differences in productivity. For example, identical semi-conductor assembly lines in Houston and Tokyo show a 15% difference in productivity. Absenteeism and turnover averages 25% to 50% lower in the Sony San Diego plant when compared to other electronics firms in the area. Five characteristics distinguish the Japanese management style:

(1) Emphasizing a flow of information and initiative from the bottom up;

(2) Making top-management the facilitator of decision-making rather than the issuer of edicts;

(3) Using middle management as the impetus for and shaper of solutions to problems;

(4) Stressing consensus as a way of making decisions;

(5) Paying close attention to the personal well being of employees.

While all of these characteristics could not be adopted immediately by American shipyards, American managers can learn from the Japanese managerial techniques on possible ways to improve productivity.

It is the job of the industrial engineer, who is at the point of application, to be aware of new developments in management thought and practice and bring the contribution of functional specialists to bear on the situation as he finds it. Often the problem has all of the awkward ingredients of real people, existing machines and the need to improve efficiency and cash flow. The new role of the industrial engineer was emphasized in an address by P. S. Moore, Proctor and Gamble Vice President. "The Industrial Engineer we see in the 1980’s is a manager of the engineering environment, be he or she serving in a staff role or as an executive.”

The potential impact on the firm of the industrial engineer working through the management function has to be rated a three. There is no where that the creative individual can make a greater impact on the firm than through integrating the industrial engineering functions with sound management.

MANAGEMENT BRIEFING ON INDUSTRIAL ENGINEERING

FUNCTIONS OF INDUSTRIAL ENGINEERING

Conclusions

In examining the functions of industrial engineering which lead to increased productivity, both the technical and the human element of the production process have been considered. The industrial engineer uses the theory of technology and translates this theory into practice. This process is implemented through the employees. The industrial engineer is uniquely trained to work at this man-machine interface, integrating the necessary functions to improve productivity. However, the question can be posed as to how all of these activities could impact shipbuilding.

The cumulative impact of technology is illustrated in Figure 1. The largest gains in impact or payoff are usually realized early in the application of these functions. It is not uncommon to achieve 75% of the savings attributable to a function through the initial 25% of the effort. After that point, it often becomes a process of refinement rather than breakthrough, although refinements can result in significant savings.

The human impact, as illustrated in Figure 2, shows a payoff which builds with experience and trust. Curve A represents such an impact on productivity improvement. Herbert Simon, Nobel Laureate, has estimated that 25% of our productivity improvement is achievable through the technical functions, while 75% of the potential improvement will come through human or behavioral functions. Yet, for all of our technical success, we have done an inadequate job in developing behavioral theory and successfully relating that theory to the work place. An example of this problem is shown by Curve B. Here the early impact of management's concern for the employees quickly dissipates when that concern is not nurtured and sustained. This is the well known "Hawthorne" effect.

Figure 1: Technology Impact

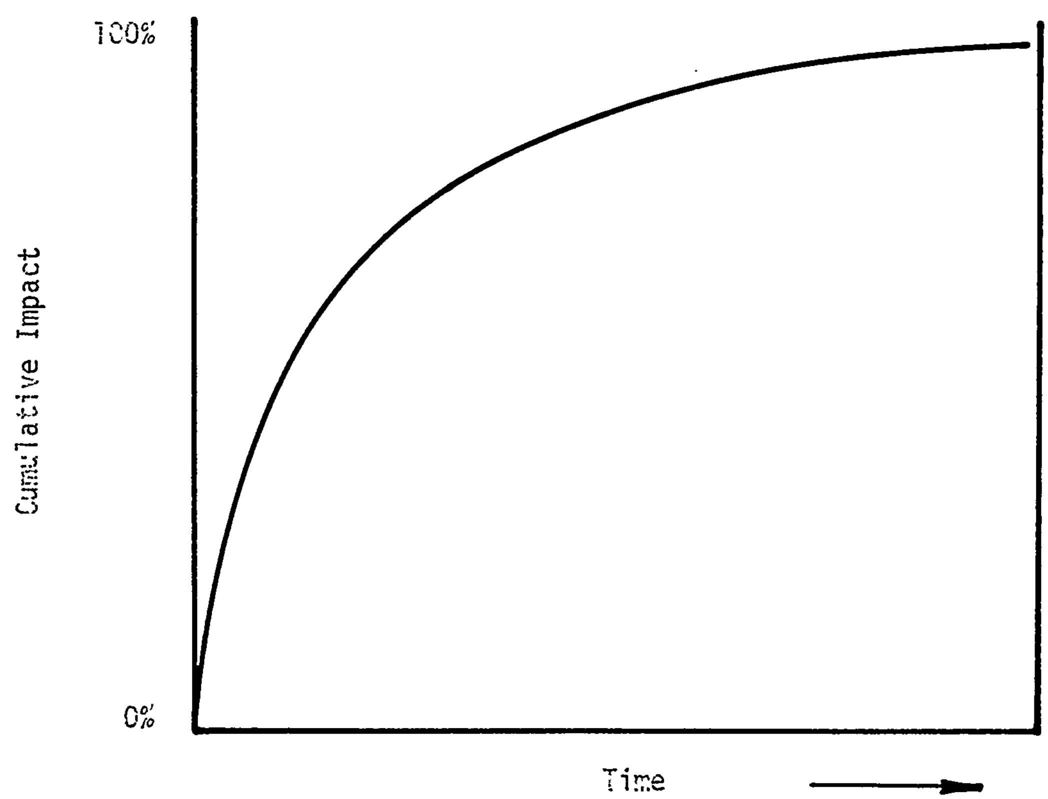
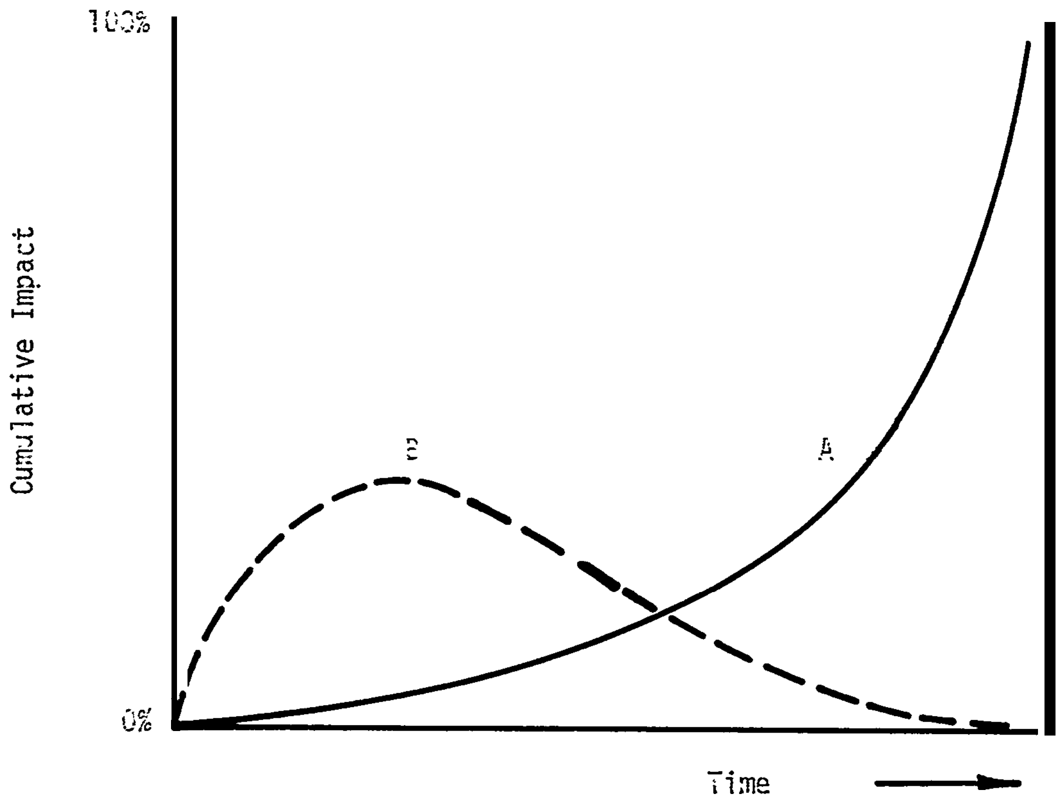
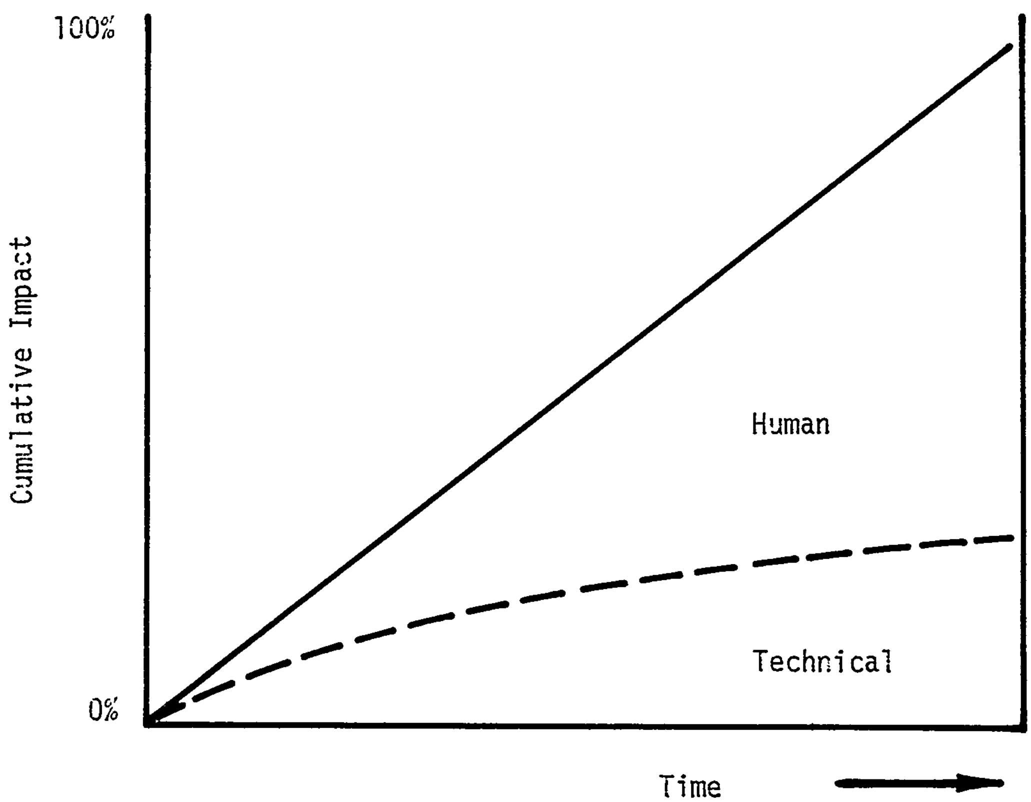


Figure 2: Human Impact



The combined effect on productivity improvement through the sound application of the techniques found in both the technical and human functions is illustrated in Figure 3. This combined effect can provide an ever improving productivity and profitability for our shipyards. The potential is there, we only have to exploit that potential.

Figure 3: Total Impact



MANAGEMENT BRIEFING ON INDUSTRIAL ENGINEERING

From Here to There

"Winning isn't everything--it's the onlv thing."

Vince Lombardi

At some time in the life cycle of every organization, its ability to succeed in spite of itself runs out. No product is safe from technical obsolescence or changing market demands. No monopolistic position is so secure that it cannot be destroyed. No one has yet to show that there is life after death for a corporation. Consequently, a business enterprise must change with the times or watch time pass it by.

To forestall stagnation and maintain viability, shipyard managements are re-evaluating their operating procedures. Supporting these efforts are organizations such as MarAd which seeks to coordinate the efforts of shipyard managements to develop a sound future for U. S. shipbuilding. Shipbuilding is an important factor in both national and local economies. Just in Texas alone, there are 60 shipyards ranging from family-run businesses employing as few as six people to large operations employing more than 2000 workers. The products of these yards vary from small fishing vessels and crew boats to ocean-going merchant ships and large offshore drilling rigs. Annual estimated Texas shipbuilding and repair industry payroll was over $240 million for 15,000 employees. This is a 28% annual growth in payroll over the past three years. With an economic impact of this magnitude in just one state, the impact on the national economy is significant.

Shipbuilding is a cyclical industry. Marine repair fluctuates seasonally. Rig construction follows the cycle of offshore exploration, providing periods of intensive demand coupled by unpredictable periods of inactivity. Military construction varies with the country's and world's political climate. New

commercial ship construction is just coming out of the catastrophic slump triggered by the 1973 oil embargo. Edward F. Paden, President and Chief Operating Officer of Livingston Shipbuilding Company, has stated that he does "not expect the world's shipyards , now greatly diminished in size, to be back to full health before 1982 at the earliest. Further, even with the substantial financial incentives to U. S. shipowners to build U. S.-flag ships intended for foreign trade in U. S. yards, it is still generally less expensive to build in foreign yards."

Considering the impact of shipbuilding on the nation's economy and the fact that U. S. shipyards are not necessarily cost competitive compared to foreign yards, the increasing adaptation of industrial engineering techniques comes at a particularly appropriate time. The creation of the Shipbuilding Industrial Engineering Panel, SP-8 is an excellent first step in implementing an industrial engineering program.

This briefing has been part of the program to increase industrial engineering awareness among shipyard managements. At this point in the briefing it is appropriate to examine

1) Where are we now?

2) Where would we like to be?

3) What must we do to get there?

Where are we now? The February 1978 seminar in Atlanta and the minutes of the SP-8 panel show a wide variation in the development of industrial engineering departments in shipyards. The majority of industrial engineering functions are being addressed to some degree by shipyard employees. However, many of these functions are assigned to independent operating groups. Such independence does not promote the integration of functions provided by an industrial engineering organization. It is this ability to interrelate functions such as methods engineering, production control and information systems which

provides the payoff from using industrial engineers. This payoff would be in increased productivity and shipyard profitability. The use of industrial engineers to develop standard times and methods is an example of the savings which could be achieved. Even with the pilot MOST effort, it is obvious that the potential savings from industrial engineering efforts are significant.

The current status of industrial engineering activities in shipbuilding is then characterized by (a) separation of functional activities between departments, and (b) experimentation with implementing the basic industrial engineering function, work measurement and methods engineering.

Where would we like to be? William Ross once said, “Why not spend some time in determining what is worthwhile for us and then go after that?” Why not indeed? If we serve ourselves and our company well, we will also contribute to the public good. Engineering is an art that uses science for the service of mankind. Industrial Engineering serves mankind by maintaining the health of our competitive enterprises. It improves our operations to increase the odds of economic survival.

The ideal situation would be for each shipyard to have an aggressive and coordinated industrial engineering effort, in a well-defined and unified organization. This organization would be staffed by industrial engineers who would have training in a particular industrial engineering specialty, but would be assigned product line responsibility. The industrial engineering effort would be coordinated from the assistance provided management in developing the strategic plan through the improvement of "shop-floor" methods and procedures.

In actual practice there would be two levels of industrial engineering that work closely together. The “staff level” industrial engineer would be a functional specialist and would be concerned with examining new concepts

and theories. He would determine which of these developments would be appropriate to apply to a particular operation within the shipyard. The task of actually applying industrial engineering techniques to yard operations would be the responsibility of the “plant level” industrial engineer. The plant level industrial engineer would be primarily concerned with day-to-day operating activities and problems. He would assist the shipyard manager in optimizing the company’s profit position. This optimization would occur through establishing better methods and controls while producing a quality product in accordance with the production schedule. To outline what management should expect from the plant level industrial engineer, a copy of an article by S. G. Liberty from the Proceedings of the 1979 Spring Annual Conference of AIIE is included in the Appendix of these briefing notes.

How do we get there? To reach the ideal, future industrial engineering operation, shipyard management must establish measurable objectives for that operation. Management must also develop a detailed plan of how to achieve those objectives. That plan must be communicated in a manner which will be understood by all involved parties. Because of the importance of this process, it is strongly recommended that the industrial engineering staff be involved in setting its objectives and outlining the plan to achieve management’s expectations. In this way agreement is realized and all concerned parties have a mutual stake in the success of the operation.

To achieve the desired objectives, it is necessary to have both “motivation and movement.” These can be developed through establishing an operating industrial engineering organization. One of the most effective configurations for such an organization is a mission orientation. “Restructuring the Industrial Engineering Department Objectives,” an article by Jerry McCormick is included in the Appendix of this briefing. McCormick points out that the

traditional industrial engineering organization is structured along functional lines, such as standards, methods and procedures, production control and so forth. Such a structure fits well into the traditional Frederick Taylor concept of specialization. This functional organization predominates shipyard operations.

In a multi-product environment such as a shipyard, the functional 'structure exhibits several weaknesses. The functional approach tends to emphasize the individual functional specialty over the goals and objectives of the firm. It tends to isolate the industrial engineer from other functions such as design and marketing. It also takes away his ability to integrate the various industrial engineering functions into an effective operating entity.

Because shipyards are a prime example of a product-oriented business, the industrial engineering organization would be much more effective if it had a product orientation. Then the entire effort of the industrial engineer would be directed toward producing a product at the lowest possible cost to meet or exceed customer specifications. This structure would keep paramount the strategic aspects of price, quality, credibility, and flexibility.

Reorganization and revision is like surgery. One just doesn't cut. However, structuring the most effective industrial engineering organization for each shipyard is an activity which could payoff rather quickly.

With the organization established, it must have the right kind of environment for its members to operate effectively. The environment is critical if the shipyard is to achieve the maximum benefit from its industrial engineers. The organization must command respect for what it does and how it does it. The organization must exploit the full mental and physical capabilities of its engineer if the job is to prove profoundly satisfying. Finally, the assigned tasks must by their very nature show the individual how well he is performing the task at hand.

Staffing the industrial engineering organization is not an easy task. The demand for industrial engineers exceeds the supply. Consequently, it is important that each organization make maximum use of the personnel they now have as well as those they will acquire. This effective utilization of people will be realized through leadership. Leadership after all is getting people to do things they wouldn't do by themselves. It is often amazing what employees can accomplish if given the opportunity to do the job they are capable of doing. We do need people who are going somewhere and are able to persuade other people to go with them. Shipyards will need industrial engineers who have

1. stability, guts under pressure, resilience in adversity and deep keels
2. brilliant brains and are not just safe plodders
3. commitment to hard work
4. a streak of unorthodox
5. guts to face tough decisions, including firing nonperformers
6. the quality of inspiring enthusiasm
7. speed in grasping nettles.

In order to build a dynamic organization we should spot our winners early and promote them fast. Effectiveness demands that our industrial engineering departments must be headed by individuals who command respect. "We can't afford phonies, zeros or bastards." (David Ogilvy)

What then should our shipyards expect from industrial engineering? The industrial engineer must be judged as any other professional is judged--based on performance of his recommendations when they are put into operation. The value of the industrial engineer is that he has the knowledge of the total system and how to interrelate the individual functions of industrial

engineering into a coherent operating entity to obtain maximum effectiveness from the operation.

The industrial engineering organization is responsible for planning and carrying out management directives; it should be judged on the basis of total division accomplishments. The Delco Division of General Motors charges each industrial engineer to submit and implement at least $50,000 of cost reduction items per year. Another typical cost-savings relationship is a 10:1 savings-cost payoff from industrial engineering.

To monitor the effectiveness of the industrial engineering effort to see if it accomplishes its objectives many firms conduct audits annually. Those audits include findings, conclusions, and recommendations on organizational structure, staffing responsibilities, total labor utilization improvement, and total material utilization improvement.

"From Here to There" has considered (a) where the industrial engineering organization should be in the future -- Planning, (b) how it can get there -- Implementation, and (c) what should be expected of the industrial engineer-- Evaluation. The future impact of industrial engineering is bright. Whether our economy is depressed, frought with inflation, or booming, the industrial. engineer can contribute to management's profitability objectives. Naturally, management, in concert with the industrial engineering organization, must select which projects are most appropriate for the application of industrial engineering. It is important to "hit home runs" by picking projects with the greatest payoff for effort expended. The industrial engineer through leadership in sound applications, reinforced with a positive attitude, can contribute significantly to shipbuilding effectiveness and profitability.

SUMMARY

SUMMARY

MANAGEMENT BRIEFING ON INDUSTRIAL ENGINEERING

Summary

"The uncreative mind can spot wrong answers, but it takes a creative mind to spot wrong questions."

A. Jay

Albert Einstein was said to have wandered the Princeton campus saying, "if I only knew what questions I should be asking myself." The same problem holds in determining the most effective way to implement industrial engineering in shipyards. Once we determine the questions to be answered, then the answers to those questions can be found.

To seek information on how industrial engineering can contribute to shipbuilding productivity, this briefing first reviewed the development of the profession of industrial engineering. This historical review of the profession is of note because industrial engineering evolves as an activity within a company in much the same way that the functions of the profession have evolved.

The usual objective of the industrial engineer is to optimize the company's profit by increasing productivity. Because of the importance of productivity to the nation as well as to the individual shipyard, this briefing surveyed productivity and its impact on the industrial sector of this country. It was particularly important to note that increasing productivity is more than just a cost cutting program. Productivity gains depend upon both the output from the process and the resource input to that process. Increasing the output from an operation while holding the same level of materials, labor, and capital is an excellent way to increase productivity. Such increases are regularly aided and encouraged by employees. This employee participation depends upon effective management which has established trust and respect.

Since industrial engineering as a profession is dedicated to increasing

productivity, the next portion of this briefing reviewed the functions comprising that profession. The initial application of industrial engineering has been through a program of work measurements and methods engineering. The data on task times and work standards are necessary to form the data base for other functions such as production planning. The success of the pilot project of initiating the MOST system of predetermined time standards was also covered in this briefing. The cost reductions achieved through work methods and methods engineering can also be realized through the other industrial engineering functions. However, even more savings are possible through the ability of the industrial engineer to integrate the I. E. functions so that the total is greater than the sum of its individual parts.

Returning to the individual industrial engineering functions, these functions were divided into two groups. The technology and systems grouping supplies the analytical techniques and models necessary to solve the complex production problems found in shipbuilding. The second grouping was human and technology. These functions provide the critical human input to operating systems. The human factor impact can exceed the quantitative impact by as much as a three to one ratio. This impact is realized through the efforts of effective management. Much of this impact differential is attributable to human variability and potential.

A subjective.rating of the possible impact of each of the functions of industrial engineering on shipyard operation is shown in Figure 1. These subjective ratings are an indication of which functions might receive the greatest initial emphasis in shipbuilding. The ratings also indicate a possible sequential order for implementing industrial engineering functions. For example, the work measurements and methods engineering function not only provides a high potential impact on productivity and profitability but also

Figure 1: Potential Impact of Industrial Engineering Functions

Function	Potential Impact
Technical and Systems	
Work Measurement and Methods Engineering	3
Facilities Planning and Design	2
Production and Inventory Control	3
Quality Control/Assurance and Reliability Engineering	3
Engineering Economy	1
Manufacturing Systems	3
Operations Research	1
Computer and Information Systems	3
Human and Systems	
Ergonomics	2
Industrial and Labor Relations	2
Management	3

provides the data base for the other industrial engineering functions. This function should be implemented first as has been already done in shipbuilding.

Now that it has been established that industrial engineering could have a potential impact on profitability in shipbuilding, how does one get “From Here to There?” In order to determine this, the questions were asked, “Where are we now? Where are we going? and How will we get there?” The trip will not be free. “You can’t hit the jackpot unless you put a few nickels into the machine.” However, the payoff of the applications of industrial engineering should be well worth the cost. The critical phases for the implementation of industrial engineering is first planning - do it right first, and operations - do it better now. Industrial engineering could well be considered as Improvement through Effort. That effort must be made through dynamic leadership and management commitment.

“There are no great men. Only great challenges that ordinary men are forced by circumstances to meet.”

Adm. “Bull” Halsey

REFERENCES

REFERENCES

NO. 6 OF A SERIES

Productivity in shipbuilding

An industry-wide effort with the Maritime Administration is drawing on AIIE and other resources to identify common industry problems and develop procedures to improve productivity.

FRANCIS X. MUNGER AND JAMES R. HELMING
Bath Iron Works Corp., Bath, ME

In 1971, the Maritime Administration (MarAd) established the National Shipbuilding Research Program with objectives to improve productivity and to reduce government subsidy through the development and application of improved methods and technologies. To maximize shipyard involvement, the Program was organized into a series of sub-programs, each managed by a sponsoring shipyard charged with the responsibility for carrying out approved research projects in their specific area under cost sharing contracts. In order to ensure continuing relevance of the research efforts, overall Program direction, guidance, and project approval is provided by the Ship Production Committee (SPC) of the Society of Naval Architects and Marine Engineers (SNAME). The SPC is composed of senior shipyard managers and representatives of the Coast Guard, Navy, MarAd, and the American Bureau of Shipping.

The Ship Producibility Research Program, managed by the Bath Iron Works Corp., is one of these sub-programs. During the first five years of the Program the research efforts were concentrated on improved ship design and shipyard operations from the standpoint of construction. In 1977, it was decided that industry needs and program objectives could be better served by redirecting program efforts into the areas of shipbuilding industrial engineering, and shipbuilding standards and specifications. The structure for this redirected program is outlined schematically in Figure 1.

Shipbuilding IE Workshop

The first step in establishing an IE program was to ask the American Institute of Industrial Engineers to host a Shipbuilding IE Workshop in cooperation with the Maritime Administration and the Bath Iron Works Corp. The principal purpose of the Workshop was to bring together a representative mix of shipbuilders in order to ascertain the degree of common problems within the industry and to make recommendations as to what cooperative action might be taken toward their resolution. The Assistant Secretary for Maritime Affairs of the US Department of Commerce, Mr. Robert J. Blackwell, sent invitations to all US shipyards to attend this Workshop.

In February, 1978, some eighty representatives from twenty-two shipyards and various government agencies assembled in Atlanta for three days. The Workshop was organized around four working panels. These panels were: Production Planning, Scheduling and Control; Methods and Standards; Facilities Planning and Engineering; and Quality Control/Assurance.

During the course of the Workshop it soon became apparent that shipbuilding problems are generally not specific to one shipyard, but rather, are common across the industry. More than twenty common problem areas were identified, explored, and proposed as candidate research projects for the Ship Producibility Research Program (the proceedings of this Workshop were published and copies are available

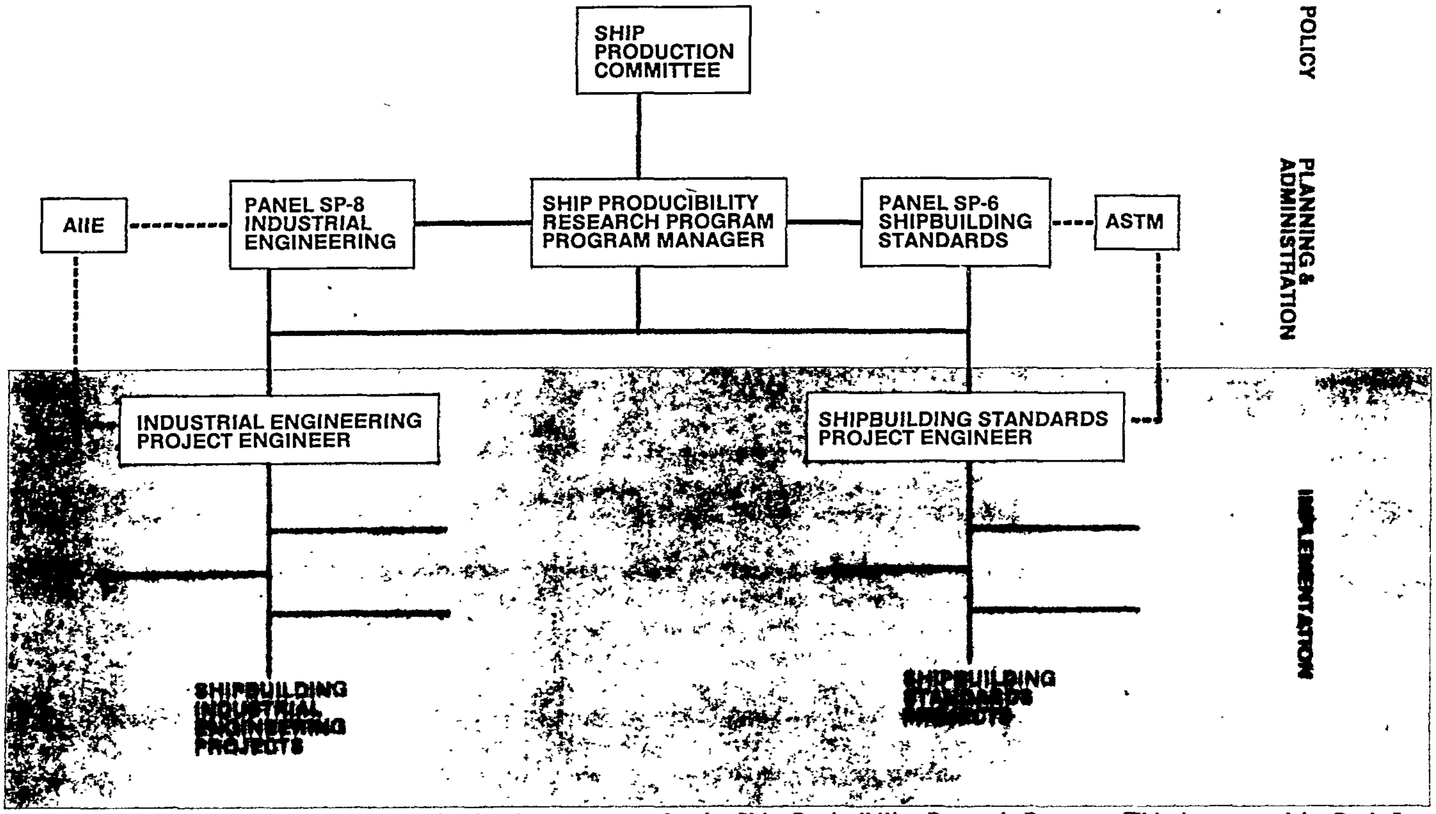


Figure 1—Chart presents organizational arrangement for the Ship Producibility Research Program. This is managed by Bath Iron Works Corp. as a sub-program in the National Shipbuilding Research Program established by the Maritime Administration.

upon request from the authors).

Shipbuilding IE Panel

A direct result of the Atlanta gathering was the formation of a Shipbuilding Industrial Engineering Panel (SP-8) under the Ship Production Committee to take action on the recommendations of the Workshop, and to carry on its intent on a continuing basis. The Panel membership is composed principally of senior industrial engineers representing fourteen US shipyards. Its key role is to act for the industry in coordinating a cooperative technical IE program with the Maritime Administration and:

- Establish a consensus priority list of problem areas for solution
- Solicit and review proposed IE research projects which address the problem areas
- Provide continuing program guidance and overview
- Publish and disseminate research results to the industry and aid in the understanding of such results
- Maintain a flexible and continuing program with built-in redirection capability to address new problems as they arise
- Maintain an up-to-date awareness of shipbuilding and industrial engineering technologies
- Schedule periodic technical meetings for industrial engineers in shipbuilding
- Develop and organize a program of training for shipyard management and industrial engineering.

At this writing the Panel has met twice and formally established a National Shipbuilding Industrial Engineering Program under the auspices of the Ship Producibility Research Program. All of the Atlanta Workshop recommendations have been reviewed and prioritized according to relative importance to the industry. The most important projects have been proposed to the Maritime Administration as research projects, and funding has been requested for their accomplishment. Some will be undertaken in the near future by participating shipyards, or where appropriate, by consulting firms.

Labor standards

The single most significant recommendation of the Atlanta Workshop was that labor standard data should be developed for fabrication, assembly, outfit, erection, and pre-outfit operations in all functional craft areas. In order to carry out this recommendation a common predetermined motion time system (PMTS) must be selected for the industry and personnel trained in its use before any labor standard data can be developed. Known predetermined motion time systems were examined for applicability to the various shipbuilding operations and a request for proposal (RFP) sent to several consulting firms. The RFP asked for bids to train personnel in a PMTS, and to provide consulting assistance for the first year of data development.

All proposals received in response to the RFP were evaluated by SNAME IE Panel, SP-8, using a standard grading system. One company's proposal was selected as the best and contract award is expected for early in 1979. At that time about thirty shipbuilders from up to twelve shipyards will begin training in their PMTS at a training center.

Upon completion of the two-week

training period, six shipyards will begin the initial development of labor standard data in selected craft areas. The data will be developed to the extent that it is uniformly applicable. Follow-on "fine tuning" of the data to include personal, fatigue, and delay factors will make it yard specific and permit the establishment of labor standards. The six shipyards that will participate in the initial data development are: Bath Iron Works Corp., Bath, ME; Bay Shipbuilding Corp., Sturgeon Bay, WI; National Steel & Shipbuilding Co., San Diego, CA; Newport News Shipbuilding & Drydock Co., Newport News, VA; Peterson Builders, Inc., Sturgeon Bay, WI; and Sun Shipbuilding & Drydock Co., Chester, PA.

Additional shipyard participation in this program is expected for follow-on labor standard data development and maintenance efforts after the first year. The use of labor standards in shipbuilding by estimators, production planning, industrial engineering, and production personnel will result in improved control of work flow and production methods, thereby reducing the time and cost of ship construction.

Educational services

Another Workshop recommendation was that training programs in industrial engineering technology should be upgraded and intensified. The AIIE has been asked to prepare a series of up to eight educational seminars for presentation in US shipyards, upon request. After evaluation by the SNAME IE Panel, SP-8, three seminars will be given in pilot presentations. Based on feedback from the pilots, all seminars will be fully developed and ready for presentation to the industry in fiscal year 1980. The proposed eight seminars under development are:

- Management Training Needs for Upper, Middle, and Supervisory Employees
- Work Force Motivation
- Work Measurement Techniques
- Advanced Facility Planning/Capacity Analysis
- Understanding QA/QC, Dimensional Control, and All Associated costs
- Network Techniques and Analysis as it Relates to Shipbuilding
- organization Responsibility, and Authority of the IE Function in Shipyards
- Current Technological Advancements in Facilities, Equipment, and Processes.

Facility capacity analysis

Based on another recommendation of the Atlanta IE Workshop, a proposal has been developed to conduct a feasibility study of shipyard facilities capacity analysis. This study is intended to examine the feasibility of developing techniques/algorithms for determining shipyard and facilities capacity analyses for planning and shipbuilding purposes. This examination will include, but not be limited to, various numerical modeling and quantitative techniques (e.g. linear programming, special purpose algorithms, queuing theory, etc.) in use in shipbuilding and allied industries. It is anticipated that if the development of an effective method for determining shipyard facility capacity analyses proves to be feasible, that it will provide a planning tool for improved facility utilization.

Other program efforts

Jeffboat, Inc. of Jeffersonville, IN, is preparing a proposal to develop an Activity Analysis Model for Shipbuilding during fiscal year 1980. Once developed, this model should prove to be an extremely useful Production tool for resource allocation. A professor has applied this type of a model to a naval ship overhaul project with encouraging results. Either he or his associate is expected to assist with this project.

Some other research projects under consideration for accomplishment in fiscal year 1980 are: An analysis of the effects of pre-outfitting and modular construction techniques upon production cost reduction. The development of an integrated shipyard labor control system. The development of consistent QA/QC standards recognized nationally by the regulatory agencies. An analysis of incentive and measured work day plans in shipbuilding.

The preceding paragraphs have described the industrial engineering portion of the Ship Producibility Research Program and some of its research projects. Admittedly, the concepts and projects discussed are not new and have been in use in other industries for years. However, they are new to the shipbuilding industry, and hopefully, their development and subsequent application will help to make the industry more competitive and productive, and lower the government subsidy rate.

Any comments and recommendations regarding this research program would be welcomed by the authors at: Bath Iron Works Corp., 700 Washington St., Bath, ME 03430; Telephone (207) 443-3311. IE

Francis X. Munger is Program Manager for the Ship Producibility Research Program at the Bath Iron Works Corp., Bath, ME. He holds a BS degree from the US Naval Academy, a BSEE degree from the Naval Postgraduate School, and an MS in Systems Management from the University of Southern California. He is a member of the Society of Naval Architects and Marine Engineers, and the American Society for Testing & Materials.

James R. Helming is a Project Engineer at the Bath Iron Works Corp., Bath, ME. His principal responsibilities involve coordinating the industrial engineering portion of the Ship Producibility Research Program. He holds a BS in Industrial Engineering and a BA in Business Administration, both from Rutgers University, and is presently enrolled in an MBA program at New Hampshire College.

Multiple activity work study needs X samples

A simple method is presented for determining sample size requirements for a desired accuracy when making a multiple activity work sampling study.

DONALD S. ALLEN II, Naval Facilities Engineering Command, Alexandria, VA

Work sampling is a flexible, cost effective work measurement technique that allows the estimation of the proportion of time an activity occurs without continuous monitoring. However, it is important to realize that the statistical theory used in development of the work sampling methodologies is based on the binomial probability distribution.[1,2,3,5,6] That is, they are geared to the analysis and evaluation of the occurrence or nonoccurrence of a single activity.

Work sampling has been widely used to study several activities simultaneously. Examples of such applications, which will be called multiple activity work sampling studies, include: determination of how employees spend their time; development of standard times for several related activities; and identifying equipment utilization patterns. The accuracy of results for these studies may be overstated if sample size criteria is based on binomial probability distribution.

Activities in multiple activity work sampling studies are defined so that one, and only one, of several activities can occur at any given point-in-time for any one person or piece of equipment being observed. The occurrence of a defined activity is dependent on the occurrence or nonoccurrence of other related activities. This phenomenon is described by multinominal probability distributions. To estimate parameters of multinominal probability distributions typically requires larger sample sizes than those required to estimate parameters of binomial probability distributions at any given confidence level.

Methodology

The number of observations required for a multiple activity work sampling study is dependent on: the number of defined activities; the true proportion of time each activity occurs; the accuracy required; and the desired confidence level (1-a). Items 1, 3 and 4 are subjective and set at the outset of the study. Item 2 is not known. An estimate of the true proportion of time must be made at the start of the study in order to determine the number of observations to be made. This estimate may be based on prior knowledge, a best guess or a preliminary study.

The method[4,7] used to determine the number of observations required to achieve the desired result in a multiple activity work sampling study is given as a mathematical model:

$$n = \left[\frac{B\, p_i\,(1-p_i)}{A}\right]^2 \qquad (1)$$

where:

n is the number of observations required.

B is the upper (a/k) X 100 percentile of the chi-square distribution with one degree of freedom, k is the number of defined activities and a is the level of significance.

p_i is the estimated true proportion of time of the i^{th} event (i = 1,...,k) that is closest to 0.5.

A is the absolute accuracy required expressed as a proportion (i.e., ±0.05, ±0.10).

Approximate values of B can be determined from Figure 1. Divide the selected significance level (a) by the number of defined activities (k). Locate the quotient on the horizontal axis, move up to the curve and left to the vertical axis where the resultant value of B is read.

Donald S. Allen II is employed by the Naval Facilities Engineering Command (NAVFAC), Alexandria, VA. He works in the industrial engineering branch which has responsibility for Navy-wide industrial engineering applications in shore activities facilities maintenance programs. Allen holds BS and MS degrees in industrial engineering and operations research from the University of Massachusetts. He is a senior member of AIIE.

Example application

The production manager of ABC Corp. is interested in determining how people on the loading docks spend their time. The plant industrial engineer is called in and together they decide that a work sampling study will be used to establish how loading dock employees utilize their time.

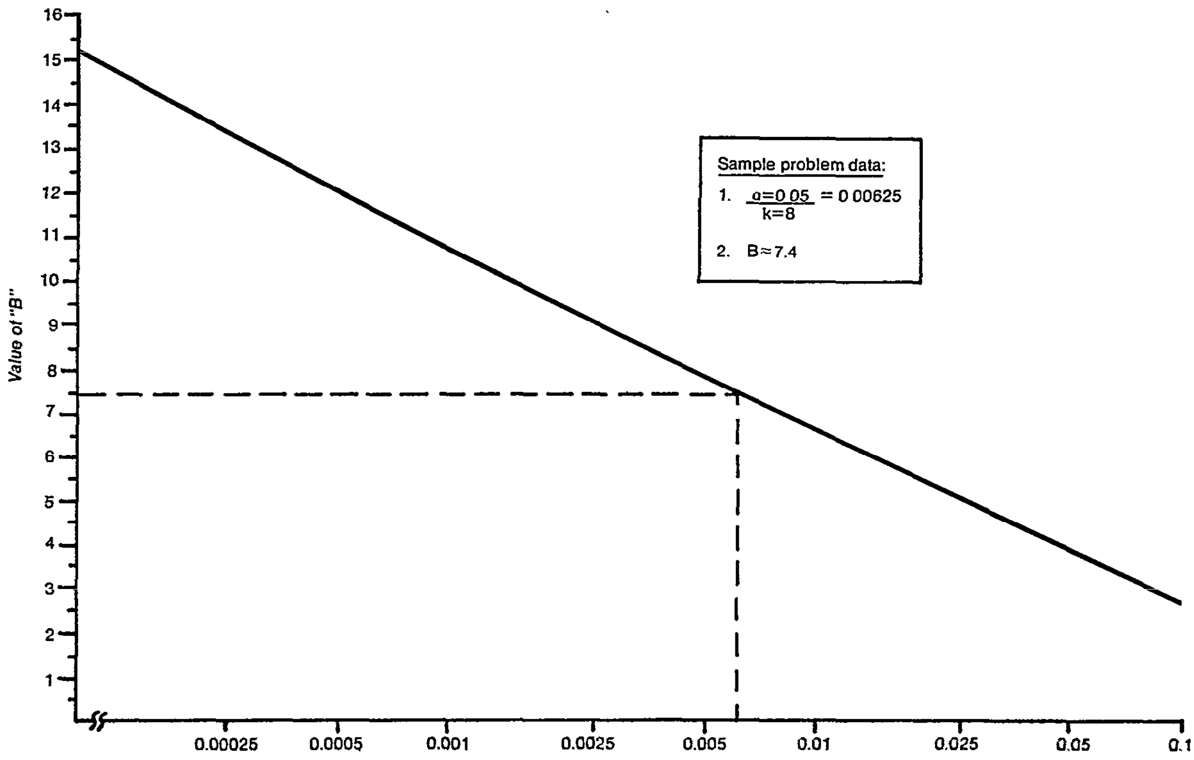
First a preliminary study is conducted to determine the parameters needed in order to conduct the works sampling study. There are five loading dock employees working five days a week 8 a.m. to 3:30 p.m. with one half hour for lunch. The principle activities of these employees are: assemble containers, pack equipment in containers, load packed containers into box cars, other miscellaneous productive time, clean up at end of day, personal time (rest, coffee breaks, etc.), work delays and idle.

The study is set up as a multiple activity work sampling study since there are eight defined mutually exclusive and exhaustive activities that loading dock employees engage in. Absolute accuracy required for this study is to be ±0.03 error in the estimated time proportion for any of the activities studied at the 0.95 confidence level.' From the preliminary study it was found that the second activity, pack equipment in containers, consumed about 35% of the time. Since this activity's time consumption was closest to 0.50, P_2 = 0.35.

Item B is also determined from Figure 1. Since the confidence level (1 – a) is set at 0.95, a = 0.05. The number of defined activities (k) is 8. Dividing 0.05 by 8 gives 0.00625. Locating this quotient on the horizontal axis of Figure 1 and working

0019 -8234/79/1200-0020$02.00/0

Figure 1. Determination of item B when level of significance and number of activities are known.



through the curve gives the value of B on the vertical axis as 7.4.

Taking the above information and inserting into equation (1) gives the number-of obserations necessary for this study. Computation of n is as follows:

$$n = \frac{[7.4(0.35)(1-0.35)]^2}{0.03} = 3,149$$

The intent of the study is to determine how loading dock employees collectively utilize their time and is not concerned with any one employee. Therefore. the 3.149 observations can be equally divided between the five employees. This means that there will be 630 observation Periods. During each of the observation periods each employee will be observed once, (i.e., five observations per observation period).

If observation times are to be random with an average elapsed time of five minutes between observation periods, then 53 hours (630 observation periods/(60 minutes per hour/five minutes averaged elapsed time)) would be required to obtain the 3,149 required observations. (In actuality if five employees were observed 12 times per hour for 53 hours, there would be a total of 3,180 observations).

If the number of observations required for the above example were computed by traditional work sampling methods, approximately 1,010 observations would have been made. Absolute accuracy in the results of the example given, based on 1,010 observations, would have been in excess of ± 0.05 at the 0.95 confidence level rather than the desired ± 0.03. The questions that may be asked at this point are: What is the additional cost in obtaining the 3,149 observations versus the 1,010 observations? Is this additional cost worth the 0.02 increase in absolute accuracy?

These are good questions but not relative. The question that should be asked is: Why is an absolute accuracy of 0.03 required? In most work sampling studies, the absolute accuracy specified is subjectively selected, and, as long as there are" no major deviations from it, the studies' results are not effected. Some studies, however, do have stringent requirements for specifying absolute accuracy. The method presented here for sample size determination for multiple activity work sampling studies, assures that required study criteria is achieved.

References

[1] Allen, D.S. II, and Corn, R. F.; "Comparing Productive Activities at Different Times;" *Industrial Engineering,* Vol. 10, No. 3, pp. 40-43, March 1978.

[2] Barnes, R.M.; *Work Sampling,* 2nd ed.; John Wiley & Sons, Inc., New York, 1966.

[3] Brisley, C.C. "Work Sampling," *Industrial Engineering Handbook,* Ch. 3, pp. 46-49; edited by H.B. Maynard; McGraw-Hill, New York, 1971.

[4] Goodman, L.A. "On Simultaneous Confidence Intervals for Multinominal Proportions;" *Technometrics,* Vol. 7, No. 2, pp. 247-254, May 1965.

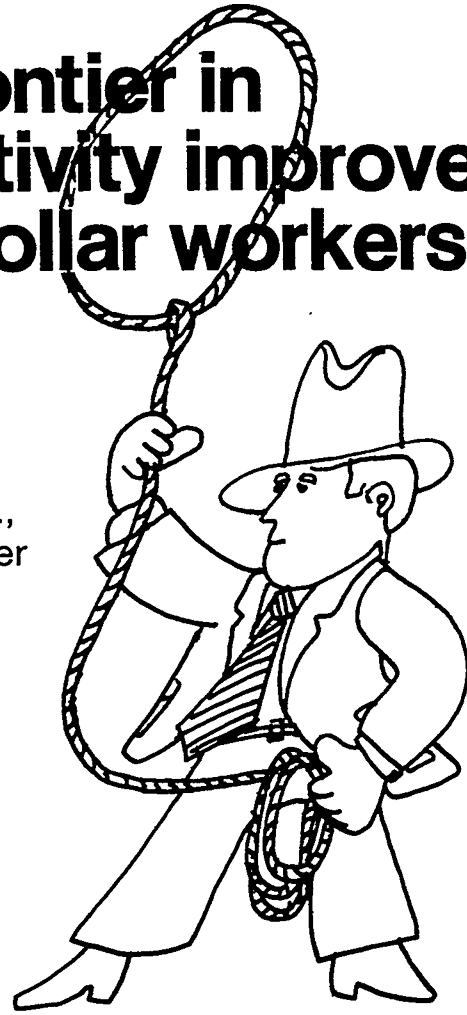
[5] Hanson, B. C.; *Work Sampling for Modern Management;* Prentice-Hall, Inc., Englewood Cliffs, New Jersey, 1960.

[6] Kinack, R.J.; "Work Sampling Tables;" *Industrial Engineering,* Vol. 7, No. 3, pp. 43-45, March 1975.

[7] Tortora, R.D.; "A note on Sample Size Estimation for Multinominal Populations;" *The American Statistician,* Vol. 32, No. 3, pp. 100-102, August 1978.

ME

New frontier in productivity improvement: white collar workers



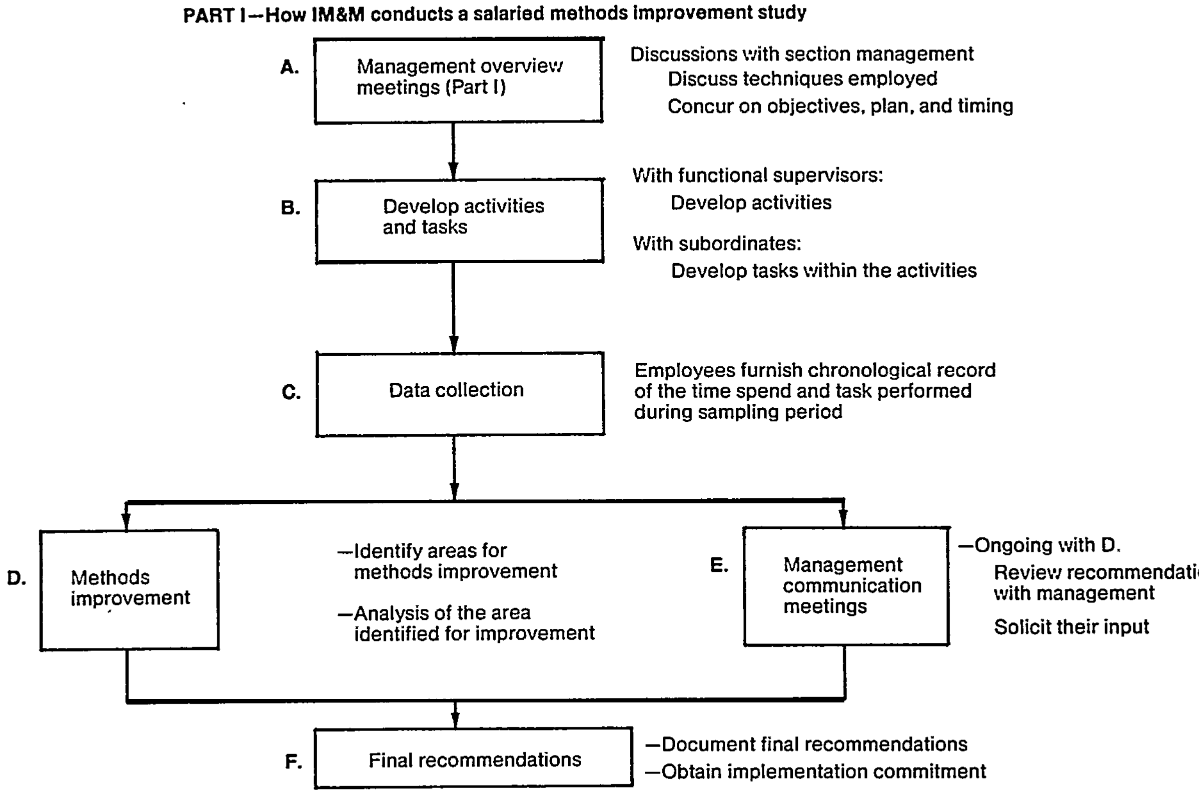
With service-oriented jobs continually increasing in the U.S., the white-collar worker becomes an obvious candidate for productivity improvement.

Bernard W. Cannan
Xerox Corp.
Webster, NY

It's no news that if American industry is to stay competitive in the world market, it's going to have to make productivity gains. But where will those productivity gains be made? The trend in industry seems to be toward decreasing the ranks of the blue collar work force while increasing the white collar labor group. Yet, with the white collar work force having grown to nearly 60% of the work force in the past decade, the majority of industrial engineering measurement programs are geared to the direct labor factors. However since 1970, direct labor productivity has improved by 96% and the clerical function only 4% (Ramellini, J.A., Advance Office Support Systems; CBS Inc.; October 1978).

Industry must recognize the fact that indirect, exempt, and overhead

PART I—How IM&M conducts a salaried methods improvement study



factors have to be addressed in conjunction with, and relative to, the direct factors. As a matter of fact, indirect, exempt and overhead labor factors must receive prime productivity consideration if U.S. industry is to reestablish its position in the world market. As business continues to grow (or at least remains steady), overhead support must shrink relative to the direct dollars being expended. In order to do this, new ways of doing business must be found.

In most situations, reductions justified or unjustified) take place every time a slack or a decline in the business cycle occurs. This usually involves removing the obvious fat or inefficiencies that have a tendency to occur during growth or prosperous times (e.g., layoffs, cut "nice to do" projects, adjust sampling plans, etc.).

Simply put, the low growing fruit in the tree is all picked during the obvious poor business cycle adjustments. Yet the hard-to-reach fruit in the high branches is what really should be the prime objective of any productivity improvement study. To get. the maximum return on any productivity study investment, the real plums are in the overhead atmosphere.

What are the methods of getting the organization revamped to be competitive with the changing world economic situation? At Xerox Corp. we've been looking at these organizations for approximately a year and have experienced a 15 to 20% increase in productivity. We have looked at accounts payable, tool design/tool control, materials management, production control, configuration control, quality control, supplier quality assurance and manufacturing engineering. In all cases we started with the premise that we weren't just conducting an efficiency study but that our motive was improving the way we do business. We felt that management determines a department's resources; we can help the department satisfy its objectives with whatever resources they have.

ACTIVITY LIST

For Work Distribution Chart

Department: ASSEMBLY M.E.	Section: MFG. ENG.	
Supervisor: Ken Jones	Prepared by: B. Cannan	Date: 7/1/78

Activity Number	Activity
1	Permanent Processing
2	Traditional I.E.
3	Line Floor Support
4	Tooling/Gaging/Fixtures/Equipment
5	Corrective Action
6	Planning
7	Administration
8	Miscellaneous

Figure 2. Activities list.

From previous experience, we know that as an industrial engineering organization if we talk about manning levels the audience usually turns off the rest of the meeting. So we promote ideas and new ways of doing business, and avoid any reference to industrial engineering terminology such as: productivity, efficiency, utilization, etc.

We use a modified work distribution analysk technique to study the various disciplines. Then activity and task lists are developed by interviewing the manager and his subordinates. The subordinates record their daily tasks against these lists to develop distribution data on where time is being spent. Using an 80/20 rule we can identify what activities give maximum return on improvements. The study team then questions every task associated with these activities, and recommendations are formalized and presented to management. Management decides which recommendations should be implemented immediately, which should become action items over a short period of time and which for various reasons won't be used at all.

Figure 1 shows a general flow diagram of how this process works. The first step is the management overview meeting in which we expose the study design to the managers involved. The technique is discussed in detail and supported by a timing schedule for the various steps of the study. The objective of the study is explained in detail. For example, in our manufacturing engineering study, the objective was stated as twofold:

l Methods improvement to increase manpower effectiveness, and

. Assurance that the department is satisfying objectives of its charter.

That may sound like a motherhood and apple pie statement of objectives, but the subtlety of the study is the avoidance of any reference to attitudes such as manpower cuts and eveyone must work hard. Instead we look for and explain to management that our technique involves these items: eliminating unnecessary tasks, combining tasks when practicable, simplifying task steps when possible and changing sequence of task steps.

Before the management overview meeting is concluded, concurrence

TASK NO.	DESCRIPTION
1	Permanent Processing
1A	Initiate PCN Package
1B	Gather Process Package
1C	Research/Review Package
1C1	Interact
1C2	Research
1C3	Review
1D	Rough/Soft/Short Run Shop Processing
1F	Hard Process
1F1	Route, Sequence Sheets
1F2	AOI
1F3	AII
1F4	Determine and record "A" tool requirements
1F5	MARF - From-to
1F6	Sketches
1F7	Update WAS System
1F8	Program and/or Make Revised NC Tapes
1G	Wrap Up Package
1G1	Make Copies
1G2	File Paperwork for own Dept's. use
1G3	Complete misc. paperwork & forms
1H	Tryout the Process
1J	Miscellaneous

Figure 3. Task list.

and management input is required on amount of improvement needed, uniqueness of area, what should be considered and acceptance of study methodology.

Figure 2 shows a sample of the activity list and Figure 3 shows a task list. The activity list is of general things that happen in an area. The task list is an elemental breakdown of each activity. The activity is developed one-on-one with the supervisor/first line manager; the task lists are developed through one-on-one meetings with the subordinates. The subordinate lists everything that he or she must do, encounter, or not do in carrying out the activity. The subordinate also has a chance to expand and provide ideas on what should change, what's stupid, I can't understand why I have to do this, and so on. This reflects the old industrial engineering philosophy that the incumbent operator is the best methods person on that job.

Next, all subordinates record their daily activity against the task listing for a period of time. This is raw data, not rated or evaluated in any way. The reason for recording time is to develop an impact on where the various workers spend their time, so that the study team can budget their effort to get maximum return for the investment.

All employees turn their time records in to their manager rather than to the study team. This way, the managers are a part of the study team and understand what's happening. They actually become more knowledgeable about the details of their area (although they don't always admit it).

The subordinates' time is rolled up in a computerized report highlighting *amount of time* and *percent of overall time* on each task. This report gives details on individual subordinates and/or each manager's group as in Figure 4.

The study team is then ready to investigate all areas where potential improvements can pay maximum returns. The team revisits the subordinates and talks in detail about what improvements are possible. The subordinate has direct input into the suggestions and serves as the expert.

Many of the suggestions must be business decisions. That is, we must determine if any activity is really necessary. Over the years jobs expand as controls are added. For example in accounts payable, receipts are kept for 7 years, authorizations have many levels of signatures, every step is usually audited, etc. These activities don't actually pay the invoice but are a periphery exercise for control purposes. A business decision would identify it as such, list the risks and the benefits, and act upon it without the justification most management would require. These are management calls with some risk involved.

Refering to Figure 1, steps A, B, and C are engineering steps. They are organized in a typical engineering approach with the purpose of defining a problem, collecting data and organizing the data into a format to be digested. Steps D and E are a deviation from the structured approach and involve more of what can be sold and how to market it,

making gut calls. The important factors are the dialogue channels between step D (methods improvement) and step E (communications). These recommendations must be communicated in a completely open and free atmosphere. A feeling of trust and cooperation must be established and maintained.

The management team reviewing the recommendations must maintain a positive approach to the study. When a suggestion is forwarded that does not meet with their approval, they can't just say, *That won't work.* They must come up with alternatives or counter suggestions. The main point of the suggestion that is presented by the study team is the fact that an area with potential is being highlighted, and although the suggestions may not provide a cure-all, with management's help some workable improvement is possible.

The suggestions which were straightforward were oftentimes cut in instantaneously. Those that affected other areas and involved concurrence were rolled up into a package and presented to those areas affected. Complex recommendations received concurrence with follow-up action items as contingencies before full implementation.

The 'entire final recommendation package is then organized into a package and presented to the vice president of manufacturing by the section manager of the discipline studied. This serves to support complete commitment by everyone to the study and allows the manager some visibility (after all, it is his study).

There are many side benefits to this type of study: indicators are developed for future manpower forecasting; accurate job descriptions are documented; manpower allocation and work distribution become easier: communications are improved across all lines; and systems and procedures are developed to accurately reflect the situation.

The overriding factor in this type of study is communications—keeping everyone informed as to what is happening with no one working in a vacuum. Let the manager bite off as much as he or she wants to chew but don't force anything down his or her throat. White collar environments do not have detailed station layouts, exact processes, etc. Evaluating all the variables and documenting all the factors involved make this type of study unique from the direct labor study. Because of these points very little has been done in this area of industry up to now, but this is where future improvements will be most justified.

The author presented this feature as part of the idea Exchange at the 1979 Fall Industrial Engineering Conference, Houston. IE

************************TARONI ************************A		HRS.	PERCENT
(AOA)	SELF EDUCATION	16.0	1.33%
(AOB)	OTHER	24.0	2.00%
(A)	MISCELLANEOUS	40.0	3.33%
(1A)	INITIATE PCN PKG	6.0	.50%
(1B)	GATHER PROCESS PKG	16.5	1.37%
(1C1)	RESEARCH/REV.PKG:INTERACT	9.5	.79%
(1C2)	RESEARCH/REV.PKG:RESEARCH	13.2	1.10%
(1C3)	RESEARCH/REVIEW PKG:REVIEW	10.5	87%
(1D)	ROUGH/SFT/SHRT RUN SHP PROC.	2.7	.23%
(1F1)	HARD PROCESS:ROUTE,SEQUENCE	68.8	5.72%
(1F2)	HARD PROCESS:AOI	12.0	1.00%
(1F3)	HARD PROCESS:AII	12.0	1.00%
(1F4)	HARD PRCS:DET&REV"A"TL RPT	1.5	.12%
(1F6)	HARD PROCESS:SKETCHES	3.5	.29%
(1F7)	HARD PROCESS:UPDATE WAS SYS	1.7	.15%
(1F8)	HARD PROCESS:PROG.REV.TAPES	42.2	3.52%
(1G1)	WRAP UP PKG:MAKE COPIES	6.5	.54%
(1G2)	WRAP UP PKG:FILE PAPERWORK	12.7	1.06%
(1G3)	WRAP UP PKG:MISC PAPERWORK	16.2	1.35%
(1H)	TRYOUT PROCESS	6.2	.52%
(1J)	MISCELLANEOUS	5.5	.46%
(1)	PERMANENT PROCESSING	247.5	20
(2A1)	MTL.HDNLG/FAC:WORK ORDERS		
(2B1)	STDS AUDIT:HI-LOW EFF.		
(2B2)	STDS AUDIT:METHODS LAYOUT		
(2B3)	MISC STDS AUDIT		
(2C)	STANDARDS ESTIMATE		
(2D1)	WORK MEASRMT:ELE		
(2D2)	WORK MEASRMT:		
(2D4)	WORK MEAS		
(2D6)	WORK		
(2E1)	ST		
(2E2)			
(2E3)			
(2E4)			
(2E6			
(2F			

Figure 4. Time results.

Bernard W. Cannan, employed by Xerox Corp., Webster, NY, has had many years of experience in industry. As a hobby he instructs business policies at a local college. Cannan holds a BS degree in production management from Rochester Institute of Technology.

TOWARD MULTI-CRITERIA LOCATION AND LAYOUT: SHIP FACILITIES LAYOUT ANALYSIS

Robert J. Graves, University of Massachusetts
Leon F. McGinnis, Georgia Institute of Technology

ABSTRACT

The ship location-layout problem is one of locating compartments in a ship in an optimal manner. It is an integral component of the ship design process used by naval architects. Two significant difficulties with respect to this problem are generating the ship arrangement plans and then evaluating such plans against specific criteria. A simplification of these problem statements is called the compartmentation problem; both evaluation and generation of the compartment plans are discussed at a conceptual level.

A procedure for evaluating compartment plans is proposed. Its major thrust is the explicit development of the various absolute and relative criteria used in the current system. A model for the compartmentation plan generation problem is the basis of the proposed procedure. It is noted that this proposed system is a tool to aid designers in making plan comparisons and in designing good plans on a more explicit basis.

INTRODUCTION

The objective of ship arrangements is to locate interacting activities, delineated as compartments, in an optimal manner. These activities interact in a variety of ways and there are numerous attributes by which an arrangement pattern is examined. The locations for these compartments are planar regions known as zones. Zones are portions of decks outlined by hull and/or structural bulkhead members and deck plans are the diagrammatic or graphical representation of the compartment locations.

Two interrelated problems are noted with regard to ship general arrangements, these are identified as deck plan generation and deck plan evaluation. A deck plan generation process gives rise to a deck plan showing the general arrangements. Feasibility considerations as to area, volume, ship stability and so forth, have been considered as part of the naval architect's decision process about location. Some form of deck plan evaluation then takes place. Modifications to the deck plan or complete new deck plans may need to be generated following the evaluation process. The interrelationship between the problems demonstrates that once a "good" design can be identified through evaluation, some information concerning the measures associated with the design can be utilized in the generation process thus improving deck plan generation. This paper will concentrate on the evaluation problem.

The evaluation of a ship general arrangement is, in many ways, quite similar to the evaluation of a layout for a plant or warehouse. There are a number of interacting activities (in this case the compartments themselves) for which relative location is important. In addition to identifying those pairs of compartments for which the interaction is important, it is necessary to specify the nature of their interaction and to indicate the relative importance. Finally, a scheme is required for assessing the merit of one plan compared to another. A starting point is to examine evaluation criteria.

Several evaluation criteria in plant layout are identified by Francis and White [31] as: minimize investment in equipment, minimize overall production time, utilize existing space most effectively, maintain flexibility of arrangement and operation, minimize material-handling cost, minimize variation in types of material handling equipment, facilitate the manufacturing process and facilitate the organizational structure. while at least a step towards specificity, these listed criteria still are difficult to measure. The check-list approach of Apple [1] and Muther [6] avoids the problem entirely by leaving the specific evaluation as an implicit process. Moore [5] considered this layout evaluation problem as the most difficult of the layout process.

Especially when there are a number of "stakeholders" (as is the case in designing something as complex and expensive as a ship) it is important to make explicit the objectives that will be used in judging a given design or in comparing two different designs. While identifying the concerns of various groups may not be difficult, it does not automatically yield a method for making the evaluation. It is clear that the difficulty lies both in the identification and the measurement of criteria and in the aggregation of these measures into a form of layout "score."

It should be noted that the problem of evaluating a ship's general arrangement is somewhat more complicated than the usual plant facility because of the nature of the "facility" being designed. A ship is a multi-floor facility, with very rigid access limitations due to the required bulkheads. In other words, access to the compartments in a given zone will be fairly limited because there will only be a limited number of penetrations allowed in any bulk-

head.

PROBLEN CHARACTERIZATION

The concentration in this research is upon formal mechanisms for layout/deck plan evaluation as distinguished from those which are informal. Hence, the identification of specific objectives to be served and the measurement of the degree to which these objectives are achieved by a given layout are quite important. Thus the problem at hand is to make explicit the various concerns in the process for evaluating designs.

In order to simplify the problem in the initial stages, consider the evaluation of a compartmentation. Such a plan is distinguished from the deck plan in that it reflects the assignment of compartments to zones without a detailed layout of each zone. The compartmentation plan is simply a list of the compartments assigned to each zone. Mathematically, the plan can be represented as a vector, $\underline{x}$ whose elements are x_{ij}, where $x_{ij}=1$ if compartment i is assigned to zone j and $x_{ij}=0$ otherwise. There are two aspects of the evaluation problem with which we are concerned. On the one hand we would like to be able to determine if a given plan, X, is a "good" one, while on the other hand we would like to be able to make a comparison between two alternative plans, $\underline{X}^1$ and $\underline{X}^2$.

Conceptually, the evaluation problem is solved if we have available to us some function, say U(x), which gives us a "score" for the plan $\underline{x}$, and a knowledge of the values of U(x) which correspond to "good" compartmentation plans. Then, for example, if there are two plans, $\underline{X}^1$ and $\underline{X}^2$, we can say that $\underline{X}^1$ is better if and only if $U(\underline{X}^1)>U(\underline{X}^2)$. This is essentially the approach used in computer-aided layout methods such as ALDEP, CORELAP, CRAFT, and PLANET [7].

In these programs, the layout plan can be described either by an adjacency matrix or by listing the centroids of the departments. In ALDEP, for example, the score is the total preference rating for departments which are adjacent in the layout. CRAFT, on the other hand, evaluates the total cost for required item movement based on the (rectilinear) distance between the department centroids.

The problem can be further characterized as one involving decisions with multiple objectives. In the past, single objectives, typically one of those suggested earlier, were optimized while other objectives were often only sufficed [7] if considered at all. An additional form of characterization is that of a problem under certainty in the sense that the multi-attribute consequence of each alternative in the form of a deck plan is known with certainty and we are considering the trade-offs associated with the achievement of one objective or another. Such a problem is distinctly different from one with uncertainty about the consequences of the actions taken. Finally, a third characterization involves the number of decision-makers involved. These characterizations are displayed in Figure 1. In the material that follows, the problem considered is one having multiple objectives with known consequences of each alternative and a single decision-maker involved.

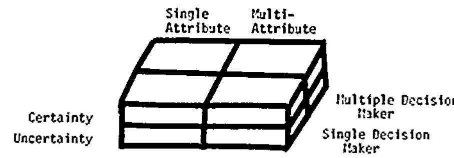


Figure 1

Several major "objectives" in deck plan evaluation can be identified, namely to maximize performance of the layout, to minimize the costs associated with its operation, and to minimize the construction cost through design. These would characterize the broad "areas of concern" of the decision-maker and fall within the framework used by Keeney and Raiffa [4] to define objectives. These objectives however, provide little specific information as to a procedure for deck plan evaluation and must therefore be further detailed.

For example, it is desirable to minimize the amount of wiring which means that equipment connected by wiring should be located as close as possible. A similar concern could be expressed for ventilation, plumbing, etc. A second area of concern is the cost of operating the ship. One way to view this is as a desire to minimize the amount of travel required by the ship's personnel in discharging their daily duties. For example, the food lockers should be located near the galleys to minimize the amount of travel. For Navy ships, perhaps the most important concerns deal with the combat related performance. Examples are the time required to come to battle stations, the effective sustained rates of fire, survivability, etc. The objectives should each have an associated "attribute" that indicates the degree to which the alternative deck plans achieve the objective. Hence, the attributes represent measurable scalar quantities.

These attributes would ideally be objective (as distinguished from subjective) in the sense that they have a commonly understood scale of measurement. Also, they should be comprehensive in the sense that knowledge of their levels can be associated with the extent to which an overall objective is achieved. Figure 2 characterizes the set of attributes associated with deck plan evaluation.

Performance Attributes	Operating Cost Attributes	Construction Cost Attributes
Exterior-Interior Adjacency Functional Adjacency Longitudinal Displacement Passage Adjacency Safety Adjacency Transverse Displacement Vertical Displacement	Environmental Adjacency Manpower Efficiency	Electrical Adjacency Noise Adjacency Plumbing Adjacency Thermal Adjacency Ventilation Adjacency

Figure 2

Finally, it is necessary to characterize the solution procedures for these multi-attribute decision problems. It has been noted that these usually have a limited number of predetermined alternatives. The alternatives have a level of achievement of the attributes associated with them and it is these achievement levels that will form the basis of a final decision. Solution techniques, in progressing to a final selection of the "best" alternative, usu-

ally involve inter- and intra-attribute comparisons. Dominance considerations constitute one class of solution methods. Consider the two alternative plans, $\underline{X}^1$ reflecting attribute values $(x_1^1, x_2^1, \ldots x_n^1)$ and $\underline{X}^2$ with attribute values $(x_1^2, x_2^2, \ldots x_n^2)$, then $\underline{X}^1$ dominates $\underline{X}^2$ whenever:

a) $x_i^1 \geq x_i^2$ for all i

and b) $x_i^1 > x_i^2$ for some i.

It is to be noted that these scalar values of attributes are not explicitly combined into an overall score for competing designs or alternatives, and so difficulties remain in terms of selecting the best alternative from those that are not dominated. In sum, these techniques enable the classification of alternatives into two classes: those which remain active candidates for selection as optimal, and those that are not as good.

The second class of solution methods deals with the subset of alternatives that remain under active consideration. These are generally categorized as the efficient frontier and approaches to move about this efficient frontier to locate good points in terms of preferences are available in certain restricted cases. Where the frontier is convex and continuous, and aspiration levels of each attribute score can be set, an iterative procedure involving decision-maker trade-offs between what is achievable and what is desirable in the sense of attribute levels, can be utilized to approach the decision. A second procedure uses explicit linear weighted averages which vary as specific moves are made along the frontier.

These problems are not well solved in general. Keeney and Raiffa [4] point out that while the second class of methods may work well for highly structured and specialized problems, they are not very useful for most applied problems.

GENERAL ARRANGEMENTS EVALUATION

Once the set of attributes has been defined, suppose it is possible to develop for each attribute a performance function which is distance related. As an example, consider the thermal adjacency attribute just listed. We could consider the operating temperature difference between two compartments, and evaluate the thermal gradient between them. Figure 3 illustrates such a function, whose argument is distance (perhaps between centroids, or it could be between compartment boundaries). The greater the distance between the two compartments, the smaller the thermal gradient. Thus, thermal gradient can now play the role that closeness rating or item movement cost plays in many of the traditional layout procedures.

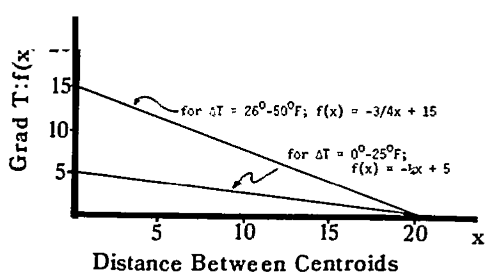


Figure 3

To abstract the notion, let C be the set of attributes, and for each attribute, $c \in C$, let $f_c(\cdot)$ be the associated performance function. Note that $f_c(\cdot)$ has distance as its argument, so that it applies to the evaluation of the distance between two compartments. Let W_c be a matrix of weights associated with attribute c, where w_{cik} is one if attribute c is relevant for compartment pair (i,k) and zero otherwise. Let D be the matrix of distances whose elements, d_{jp}, are the distances between zones j and p. The score of an arrangemnent $\underline{X}$ with regard to attribute c is:

$$s_c = \sum_i \sum_j \sum_k \sum_p [w_{cik} f_c(d_{jp}) x_{ij} x_{kp}]$$

$$\text{where } x_{ij} = \begin{cases} 1, & \text{if compartment i is assigned to zone j} \\ 0, & \text{otherwise.} \end{cases}$$

This "scoring" model can be viewed as a generalization of the single criterion scoring models employed in computer layout programs.

The result of implementing this scoring model is a vector score $\underline{S}$ for each competing design. We still do not have the function $U(\cdot)$ which will give us a simple scalar score for the designs. In fact, at this point what we still have is a multiple-attribute decision problem. As indicated earlier, these problems are theoretically very difficult, since they involve the decision-maker's judgement (or utility) and in general, the problems remain unsolved from a theoretical standpoint.

A commonly-used approach for such multi-criteria selection problems is to use some (fairly arbitrary) function to reduce the vector score to a scalar score. Various forms have been suggested for this function [4]. The one we shall use to illustrate the approach will be linear, i.e., it will be a simple linear weighting of the individual scores. From both a theoretical and an operational perspective, the key issue in this approach is the method used to determine the weighting coefficients. Assign to each attribute score a weight, w_c, and define the score for an alternative, $\underline{X}$, to be:

$$S(\underline{X}) = \sum_{c \in C} w_c \left(\sum_i \sum_j \sum_k \sum_p [w_{cik} f_c(d_{jp}) x_{ij} x_{kp}]\right).$$

Other forms for the scoring model are possible; for example, the criterion scores might have a multiplicative rather than additive relationship. As with choosing computer-aided layout packages, the nature of the scoring function must be examined before selecting one approach or another. The above assumption of a linear form simply demonstrates the approach.

AUTOMATIC PLAN GENERATION

Once a scoring model is available, it is conceptually a simple matter to construct an optimization model for the ship general arrangements problem. The objective to be maximized is the value of the score, $s(\underline{x})$. There are a number of constraints affecting the decision variables, which are the x_{ij}'s. Obviously, every compartment must be assigned to exactly one zone:

$$\sum_j x_{ij} = 1, \text{ for each } i.$$

In each zone, there are limits on the available floor space and the available volume. Letting s_i and v_i be the space and volume required by compartment i and letting S_j and V_j be the space and volume available in zone j, the general arrangement must satisfy the following two constraint sets:

$$\sum_i s_i x_{ij} \leq S_j, \text{ for each } j$$

$$\sum_i v_i x_{ij} \leq V_j, \text{ for each } j.$$

It is a simole matter to exclude a compartment from certain zones by deleting the corresponding variable. It is similarly possible to consider passageway area and volume as either allocated among s_i and vi or reducing the amounts available in S_i and V_i.

In this form, the general arrangements problem can be recognized as a quadratic assignment problem. Thus, there is virtually no hope of being able to optimize the solution. However, there have been a number of models of this type which have proven useful in practice because there are good heuristic methods for solving the problem. In fact, CRAFT has been used with good result to solve quadratic assignment problems [2].

This formulation of the general arrangements problem gives us access to the various heuristic techniques and makes possible a potentially powerful interactive design process. In this process, the naval architect could specify an initial general arrangement and then use the various neighborhood search heuristics [2] to seek an improved solution (this is the basic approach in CRAFT). The important point is that by using the computer's enormous capacity for arithmetic operations, a large number of alternative arrangements could be generated and evaluated in a very short period of time.

This computer-aided arrangements design process would also interface well with the computer graphics capabilities currently being developed by the Navy's Ship 'Engineering Center. In this system, one group has responsibility for defining the hull steel, resulting in a data base containing the geometrical description of the zones. Combining this with a data base containing the compartment descriptions, the naval architect could generate the general arrangement data base (perhaps using the interactive QAP formulation). Finally, the interactive computer graphics system would access both the zone data and the general arrangements data to permit the actual layout to be developed.

SUMMARY

The modeling approach and description presented in this paper do not represent the final word with respect to this problem. Major areas of difficulty remain for study and these have been discussed. The transformation of pertinent criteria as functions of distance represents a reduction in the complexity of the general problem's multiple criteria and significantly eases the combining of these criteria into a comprehensive measure. Secondly, the importance weights and their determination provide for an explicit consideration of the trade-offs involved in the design process.

For the ship arrangements problem, fewer non-distance oriented criteria may exist than in the general facilities layout problem. However, some of the approaches described here could prove useful in extending the approaches to layout evaluation beyond those that have been traditionally used.

REFERENCES

[1] Apple, J.M., Material Handling Systems Design, The Ronald Press Company, New York, New York, 1973.

[2] Buffa, E.S., Readings in Production and Operations Management, pp. 272-290, John Wiley and Sons, New York, 1966.

[3] Francis, R. and white, J.A., Facility Layout and Location: An Analytical Approach, pp. 33-34, Prentice-Hall, Inc., Englewood Cliffs, New Jersey, 1974.

[4] Keeney, R.L. and Raiffa, H., Decisions.with Multiple Objectives: Preferences and Value Trade-Offs, John Wiley and Sons, New York, New York, 1976.

[5] Moore, J.M., Plant Layout and Design, The Macmillan Company, New York, New York, 1962.

[6] Muther, R., Practical Plant Layout, McGraw-Hill Book Company, New York, New York, 1955.

[7] Tompkins, J.A., and Moore, J.M., Computer-Aided Layout: A User's Guide, Facilities Planning and Design Division of AIIE, Monograph AIIE-FP&D - 77 - 1, 1978.

B1OGRAPHICAL SKETCHES

Dr. Robert J. Graves, is an Associate Professor of Industrial Engineering and Operations Research at the University of Massachusetts at Amherst. He has published papers on facilities planning in educational institutions, location models for pollution monitoring equipment and the multiple criteria associated with many location and layout problems. He is currently involved in a Maritime Administration research project on production planning in shipyards and is Principal Investigator on a U.S. Navy Ship Arrangements Project. Dr. Graves also has experience as a consultant on production planning and facilities planning problems. Dr. Graves is the Research Chairman of the Facilities Planning and Design Division of AIIE and serves on the College-Industry Council on Material Handling Education. He is a Senior Member of AIIE and a member of ORSA, TIMS, ASEE, and SNAME.

Dr. Leon F. McGinnis, Jr., is an Assistant Professor of Industrial and Systems Engineering at the Georgia Institute of Technology. His teaching and research activities are in the general areas of applied optimization and computer techniques with particular emphasis on problems arising in production, distribution, location and long range planning. He currently serves as Principal Investigator for a research project on shipyard production planning and is involved with the U.S. Navy Ship Arrangements Project. He is a member of AIIE, ACM, TIMS, and ORSA, and is Departmental Editor for Applied Optimization for AIIE Transactions.

MANUFACTURING SYSTEMS PLANNING - THE KEY TO PRODUCTION CONTROL

Robert P. Davis

J. M. A. Tanchoco

Marvin H. Agee

Richard A. Wysk

Department of Industrial Engineering and Operations Research

Virginia Polytechnic Institute and State University

Blacksburg, Virginia 24061

Abstract

This paper presents an overview of research directed toward a better understanding of the interrelationships that must be considered in planning a manufacturing system. The key element in system planning, yet the one most frequently omitted, is that of designing for production control.

Introduction

In recent years, industrial engineers have successfully employed analytical techniques to a broadening range of problems in the planning, design and control of manufacturing systems. These applications have led to the development of new mathematical models of operational systems, and have shown the utility of modern methods of systems analysis (such as direct optimization techniques and digital simulation). However, in perspective one is struck by the discriminations made between decision issues which are addressed in "planning", those addressed in "design", and those which are addressed in the "control" of manufacturing systems. A typical categorization of these decision issues might appear as shown in Table I. This is not intended to imply that industrial engineers have not recognized the interdependence of these decision issues; but rather, that a research and development basis did not exist to provide guidance to the engineer for addressing these issues in an integrated manner. Recently, a number of researchers have produced modelling and analysis results which begin to alleviate this problem.

In the authors' opinion, the fundamental decision issues of systems design and control should be addressed, in an integrated manner, as part of the manufacturing systems planning process. Material flow paths and flow rates, equipment component design specifications, and machine processing rates are all interrelated; and decisions regarding them should, to the extent possible, be done in an integrated manner. The purpose of this paper is threefold. First, the need for and potential impact of an integrated consideration of production planning, design and control decisions will be discussed. Second, current research directed toward facilitating the integration of these decision issues will be described and supplemented with a current bibliography. Finally, potentially fruitful areas for further research will be identified and discussed.

TABLE I

Categorization of Manufacturing Systems Decision Issues

Planning Decisions
- Process Planning (Machining Parameters, Process Selection)
- Flow Characteristics (Product, Process, Departmentalization)
- Machine Requirements (Number of Machines, Type of Machines)
- Materials Handling (Type of Equipment, Number of Units)
- Material Requirements (Quantity: Raw Materials, Parts, etc.)
- Aggregate Space Requirements

Design Decisions
- Machine Selection and Operating Specifications
- Machine Layout and Location
- Product/Material Flow Sequencing
- Unit Load Characteristics
- Material Handling Equipment Specifications
- Inventory Quantities and Location
- Space Requirements-Location, Orientation

Control Decisions
- Process Sequencing Variations
- Line Balancing
- Production Scheduling
- Inventory Control
- Processing and Materials Handling Rate Variations
- Maintenance Scheduling

Two key factors will be emphasized in the succeeding discussion. First, there is a need to develop more comprehensive normative models which capture the impact of design and control decisions on manufacturing system performance. Second, analytical techniques must be developed (and/or refined) which permit the system's planner to arrive at an optimal

design which is consistent with the adaptive nature of the production control process. To accomplish both of these goals, an emphasis must be placed on the explicit consideration of specific production design and control decisions in the planning stages of manufacturing systems development.

In scope, this paper deals primarily with batch-type, discrete part manufacturing systems. Particular emphasis is given to research related to machining (metal cutting) systems. The principal reason for this focus lies in the fact that the research basis for this paper is directed almost exclusively to manufacturing systems which exhibit the above characteristic.

<u>Systems Planning, Design and Control Research</u>

In this section, SeVeral areas of current research are identified and described. In total, this research represents a greater emphasis on the consideration of production control issues in the modelling and analysis of manufacturing systems. As yet, one cannot conclude that a basis exists for the optimal planning of manufacturing systems; however, significant progress can be documented that represents a broadening in the scope and level of detail addressed by current researchers in systems planning and design.

AUTOMATED PROCESS PLANNING

Process planning has been defined as: "The subsystem responsible for the conversion of design data to work instruction" [57] . In general, the process planner or engineer dictates the processes, machines (and the operating information) and, therefore, the operating rates for each component of a product. The impact of the process engineer's decisions on manufacturing cost and profitability is obvious. Yet in spite of this individual's contribution to the profitability of a specific product, little emphasis has been directed toward this planning subsystem until recently. Automated process planning systems in metal machining are a relatively new development whose impact is becoming quite noticeable.

Automated process planning systems can be divided into two basic schemes - variant and generative planning systems. Perhaps the best known process planning system is one that was developed under the sponsorship of CAM-I, the CAPP System. The CAPP system is essentially a data management and retrieval system. The system is driven by "any" coding scheme. The code is, in turn, used to retrieve standard process plans for similar parts. The detail of the planning information might be quite exact or might similarly be quite aggregate baaed on the user's need, data requirements and coding system. CAPP, and systems employing similar logic, are termed variant planning systems since they rely on varying codes to retrieve standard information [30].

Generative process planning systems are usually more detailed and have further capabilities as well as additional coding requirements. A generative planning system attempts to represent the logic process of a process planner and define the detail of part production in an optimal manner. Several benefits can be derived from generative planning systems that cannot be obtained from variant systems, The moat noteworthy of which is that optimal plans can be derived not only with respect to the process but also with respect to the machining parameters (feed, speed and depth of cut). See reference [57].

An example of this optimization capability could be represented as shown below. Total production time per part, T_p, is given by

$$T_p = T_{u/uL} + T_c + T_d \left(\frac{T_c}{T}\right)$$

where

- $T_{u/uL}$ - time to load and unload the part
- T_c - time in cut
- T_d - tool change time
- T - tool life

For hole producing, turning and boring operations this can be expanded, using the Taylor tool life equation $\left(T = \frac{C}{V^\alpha f^\beta d^\gamma}\right)$, to:

$$T_p = T_{u/uL} + \frac{\pi D \ell}{f \cdot V} + \frac{T_d \pi D \ell V^{\alpha-1} f^{\beta-1} d^\gamma}{C}$$

where:

- D = diameter of the hole or part
- ℓ = length of the hole or part
- f = feed rate
- V = cutting speed
- d = depth of cut
- α, β and γ are tool life exponents

For a minimum production time objective this becomes

$$\min_{V,f,\&d} \; T_p = T_{u/uL} + \frac{\pi D \ell}{f \cdot V} + \frac{T_d \pi D \ell V^{\alpha-1} f^{\beta-1} d^\gamma}{C}$$

subject to:

1) machine restrictions for V, f, and d,
2) power restrictions - h(V,f,d),
3) surface finish restrictions - g(V,f,d), and
4) tool restrictions

Since all of the information necessary to minimize the production time must be known to plan the part, the computational capabilities of the computer can be employed to optimize this expression, while planning the part. Standard optimum machining time could also be attained from such a piece of software. For example see references [8,19,26,27].

Optimization of machining parameters is a focal concept in both process planning and actual part production. Recent emphasis in computer-aided

manufacturing, and particularly in automated manufacturing systems, demonstrate this clearly through attempts to develop adaptive controlled machining systems.

ADAPTIVE CONTROL

Adaptive control of manufacturing processes is not a new concept; however, its adoption as a common manufacturing practice is far from widespread. It should be noted that adaptive control is differentiated from feedback control in that an adaptive control system uses feedback information to adjust processing parameters to achieve some "optimum" in system performance (i.e., minimum processing time or cost) [23,54]. Both feedback control and adaptive control applications have been most prevalent in systems which employ Direct Numerical Control (DNC) and Computer Numerical Control (CNC) equipment for discrete parts manufacturing. Although it may be true that adaptive control and DNC hold great promise as means for increasing productivity and manufacturing cost effectiveness, their potential is, as yet, unrealized.

Part of the difficulty associated with the adaptive control of machining processes, for example, lies in the development of sensor technology which will permit system states (e.g., tooll/workpiece interface temperatures) to be monitored with fidelity in a feasible real-time control domain. In addition, the impact of interrelationships in sensor response times (and fidelity), optimum control parameter determination, servo-motor control adjustments and workpiece variations on system performance is not well understood. Recently, Wysk, Kimbler and Davis [54] demonstrated that adaptive control system performance characteristics (i.e., production time, tool wear) could be examined through simulation; and the relative impact on performance due to variations in control loop components thereby determined. Unfortunately, little empirical evidence exists which can be used to verify the results which such studies produce. In effect, information from this study can be used to evaluate the relative criticality of adaptive control loop components, but not the operational cost effectiveness of adaptive controlled machining.

MACHINE REQUIREMENTS PLANNING

In general, the machine requirements planning problem can be defined as the specification of the number of each type of machine required in a production process, or group of processes, in each period of some planning horizon [331. The significance of this problem is highly dependent on the type of production process and its complexity. Typical information which has been employed in the development of models for machine requirements planning includes: operating rates of individual machines, production cost and defective produced as a function of the processing rate, machine investment cost, and space requirements. However, information on the variability of operating rates and associated costs are the key elements which relate production control information to the facility planning and design issue of machine requirements specification.

Morris [36] was the first to pose a normative model for resolving a machine requirements problem; and later, Bartlett [4] proposed a method for linking production control information to machine operational characteristics. However, these early research efforts were not immediately extended to include system planning and control issues of a general nature. Recently, Miller and Davis [17,34] have posed normative models for machine requirements planning which address such issues as varying the number of machines over time, as production demands vary; and, more importantly, of relating operating rates and in-process inventory levels to machine requirements planning for serial manufacturing systems. Hayes [27] has shown that models of the form developed by these researchers can be solved expediently using a dynamic programming approach. A characteristic form of this deterministic model is given below for an "N" stage serial system.

TABLE II

Notation for the Machine Requirements Model

N = the number of machine centers in the system

r = a feasible operating rate from a set R at stage i

$C^s_{r_i}$ = manufacturing cost for one hour of production at rate r_i during the first shift ($/hour)

$C^o_{r_i}$ = manufacturing cost for one hour of production at rate ri during the second shift ($/hour)

b_{r_i} = percent of defective units incurred at stage i by processing at rate r_i

C_{F_i} = **fixed cost of a machine per day in stage i** ($/day)

n_i = number of machines utilized in stage i

$t^s_{r_i}$ = number of hours of operation at rate r_i during the first shift

$t^o_{r_i}$ = number of hours of operation at rate ri during the second shift time period.

The objective is to minimize:

$$\text{Total Cost} = \sum_{i=1}^{N} \sum_{r\varepsilon R_i} (\underbrace{C^s_{r_i} t^s_{r_i} + C^o_{r_i} t^o_{r_i}}_{\text{processing cost}}$$

$$+ \underbrace{C_{F_i} n_i}_{\text{equipment cost}}).$$

subject to the following restrictions, for i=1, ..., N.

First, the total number of units processed at stage i must equal the quantity available for processing at that stage,

$$\sum_{r\varepsilon R_i} r_i(t^s_{r_i} + t^o_{r_i}) = S_i.$$

Second, the quantity of output product at a stage, quantity processed less the fraction defective, must equal the quantity processed by the next stage,

$$\sum_{r\epsilon R_i} r_i(1 - b_{r_i})(t^s_{r_i} + t^o_{r_i}) = \tilde{S}_i = S_{i+1}$$

For the final stage this restriction takes the following form,

$$\sum_{r\epsilon R_i} r_N(1 - b_{r_N})(t^s_{r_N} + t^o_{r_N}) = \tilde{S}_N = \textbf{final demand}$$

Finally, the units being processed at a stage cannot employ more processing time than is available on the number of machines allocated to that stage. For the first shift operation this is:

$$\sum_{r\epsilon R_i} t^s_{r_i} \leq 8n_i$$

and for the second shift operation,

$$\sum_{r\epsilon R_i} t^o_{r_i} \leq 8n_i, \text{ and}$$

$$t^s_{r_i},\ t^o_{r_i},\ n_i \geq 0 \text{ and } n_i \text{ an integer}$$

Recognizing the limitations of deterministic models for resolving systems design problems which relate operational behavior to machine requirements issues, Reasor, Davis and Miller [43] demonstrated that a combination of simulation experiments and normative modelling could lead to optimum machine requirements decisions based on the stochastic behavior of an actual, serial machining system.

MATERIAL HANDLING SYSTEM SELECTION AND ANALYSIS

Recent developments in the machine tool industry have accelerated the need for a better understanding of the role that material handling equipment plays in the flow of parts through the different production stages in a manufacturing facility. As more automated machine tools with higher production rates are developed and installed, resultant production bottlenecks will appear on transfer devices such as conveyors, and other handling devices. Once these systems are selected and installed, they become the constraints that a company must live with unless it is willing to make additions or reinstall new equipment, a process that can result in a significant capital expenditure. The need for better equipment selection procedures is therefore apparent.

The selection of a material handling system (or systems) fundamentally consists of two separate, but dependent phases:

1) the selection of the material handling equipment items, and
2) the selection of the operating characteristics for the particular handling system.

The process of selecting a material handling system for a manufacturing facility normally proceeds by first making a macro-type analysis of product mix and volume to determine the basic type of handling system required. For example, if the number of products produced is large and the quantity of each is judged low to medium, then a truck-pallet-rack handling system is suggested. The combination of few products and medium to high volume of each suggests that a conveyorized system is most appropriate. In the usual case, different basic material handling systems for different functional areas within the manufacturing facility are warranted. That is, the handling requirements in the areas of receiving, storage, processing, packaging, and warehousing may dictate different handling systems that must interact effectively as an integrated plant system. After the basic handling system (or systems) is decided upon, individual equipment items are then specified.

The material handling equipment selection process is complicated by a variety of factors - a principal one being the fact that a multiplicity of equipment types, with variable coats and degrees of flexibility, can perform a given handling task. Further, at a more fundamental design level, there are many combinations of hardware components and unit loads which will satisfy the requirements for a specific handling system. As an example, if containers of parts are to be transported between two production machines at a given rate by a horizontal belt conveyor, a large number of combinations of container sizes, belt widths, belt materials, methods of belt support, drive units, and pulley configurations will satisfy the desired rate of tranasfer.

Another factor that further complicates the design of material handling systems for a manufacturing facility is the lack of readily available, specific operating and cost data which is necessary to economically evaluate alternative handling plans [45].

The criticality of the material handling function is being recognized more and more by management and by researchers in the area of manufacturing systems analysis and design. Some of the recent research on material handling as an integral part of the manufacturing system is reported in the following section.

Network Analysis

To date, computer simulation remains the primary tool for the analysis of integrated manufacturing systems. The complexity of the manufacturing environment precludes the development of a complete analytical model at this time. Among the first computer simulation models developed specifically for manufacturing systems are GCMS (General Computerized Manufacturing Systems Simulator [28]), and CAMSAM (A Simulation Analysis Model for Computerized Manufacturing Systems [46]). GCMS is a GASP IV based simulation program that is capable of modelling much of the details of a computerized manufacturing system such as: different types and numbers of machine tools and material handling devices, different production sequencing and

scheduling rules, alternative inventory capacities, alternative system layout, etc. CAMSAM is a Q-GERT based simulation model, and is capable of performing many of the same functions that GCMS performs. CAMSAM, however, is a more aggregate model of a manufacturing system. At the most fundamental level of detail, CAMSAM deals only with operation rates; so, if machine or material handling differences do exist, they must be aggregated into a classification of rate change information rather than machine description. Both of these simulation models were developed at Purdue University.

Another development of the Purdue research, which is significantly more aggregate than either of the above simulation models, is CAN-Q [48]. CAN-Q is a descriptive analytical model which is capable of providing some rough, base performance statistics considering operating rates as well as the variety and number of machines but independent of the system layout.

Material Flow Analysis is another area that has received considerable attention. The stochastic nature of a plant-wide material flow system necessitates the use of computer-based simulation approaches. The state-of-the-art for the modelling of material flow systems for a manufacturing facility can best be described in terms of GEMS (Generalized Manufacturing Simulator [39]), INDECS (Integrated Description and Evaluation of Conveyorized Systems [38]), and DYNAFLO (Dynamic Flow [53]). GEMS is a FORTRAN-based simulation language which is based on the activity-on-box network modelling concept. The simulator was specifically designed for a discrete-part manufacturing environment, with consideration given to flow patterns, resource constraints, and costs. INDECS is a special purpose GASP II-based simulation program designed for the analysis of a conveyorized discrete part manufacturing system. DYNAFLO, on the other hand, is a network-based optimization procedure for modelling the dynamic flow of parts in a conveyorized manufacturing system.

The three material flow analysis techniques discussed above are aggregate in every sense. The flow rates and capacities of specific production equipment, transfer devices, and other physical units that make up the manufacturing environment under study are required inputs to these models. As such, these elements can be manipulated to examine the dynamic response of the system being observed under these new inputs.

COMPUTER INTEGRATED MANUFACTURING SYSTEMS

A Computer Integrated Manufacturing System (CIMS) can most simply be defined as a collection of machines tied together by a material handling system and controlled by a single computer or a hierarchy of computers. The intent of such systems is to replace high priced direct labor with flexible computer control. However, one of the early lessons coming from the experiences of designers and users of CIMS's is that these systems are far more complex than first envisioned.

By integrating a computer into a manufacturing system, several benefits can be derived. These benefits include direct labor savings, additional machine control, reduced production rate variability, automatic status and accounting updating, and flexibility. However, these benefits do not come without a related cost (or penalty). For instance, a system without machine operators cannot adapt to unusual and unprogrammed events. These events can often result in catastrophic system failures in which the machines and material handling system can suffer significant damage. Another major problem with CIMS's is that increased control of these systems can result in a significant impact in their productivity. Yet optimal control is still a virtual impossibility because of the inherent complexity of these systems.

Recently, considerable research in the design, planning and control of CIMS's has been undertaken; much of this research having been sponsored by the National Science Foundation. The recent literature reporting research in this area include references [6,14,22,28,39].

Directions for Future Research

The discussions in the previous sections pointed out the many facets of planning, design and control that must be considered at the outset for the effective design of a manufacturing system. The number of interactions among the numerous subsystems that make up the total manufacturing activity necessitates the use of macro-modelling techniques that can integrate these subsystems. By the same token, micro-models of these subsystems must be flexible enough to be integrated back to the macro-model. One then sees the necessity for computer control in resolving these issues. The resolution to this requirement for integration demands that a significant impetus be given to the conceptual and operational development of computer integrated manufacturing systems. Thus, a primary direction for research essential to the effective implementation of such systems lies in the modelling, both mathematical and algorithmic, of designs which integrate the functions of planning, analysis and control. Adaptive control systems represent a major step forward in this integration process, in that systems analysis and control functions must be modelled and tested to quantitatively establish the effectiveness of specific operational systems. However, to integrate the total manufacturing system under one structure would require more than machine-level information. It is envisioned by these researchers that a totally computer integrated planning, analysis and control system could feasibly be designed with a hierarchical structure. For example, with such a structure, line balancing and scheduling decisions would be made by a central coordinating computer while part transfers and machine loading control would be monitored by individual line (or departmental) mini-computers. In turn, individual machines on a line would be controlled and monitored by microprocessor based adaptive controllers. Whether such elaborate, totally computer integrated systems would be operationally feasible, much less cost-effective, is as yet undetermined. Major factors necessary to establishing their effectiveness are not only the modelling and testing of such systems to estimate their operational feasibility; but, as importantly, the determination of factors which affect their

economic operation - that is, to resolve questions related to the economics of automation and conversion to automated systems.

The methodology for economically justifying capital expenditures for production machine/equipment is well-known. The justification of capital expenditures for service machines/equipnent is perhaps less precise than the justification of production machines, but the methodology is the same. In general, investment alternatives are compared by one (or more) of several economic measures of effectiveness, and justified on the basis of incremental annual revenues or cost savings accruing to the given investment alternative over a selected planning horizon of interest. The literature on the total process of justifying and making capital expenditure decisions is immense but this literature is primarily concerned with single-item justification rather than "systems" justification.

Whether a decision-maker's concern is with single-item or systems justification, the importance of both economic factors and non-economic factors involved in the decision has long been recognized. However, as the scope of concern has increasingly broadened from single-item machine/equipment decisions to manufacturing systems decisions, various economic and non-economic factors have an increased importance in the evaluation process. To expand on this point, the terminology used by Apple [1] to categorize material handling cost factors will be helpful; namely, direct costs, indirect costs, indeterminate cost factors, and intangible factors. Briefly, direct costs are those for equipment (initial and recurring costs) and manpower, which are normally readily determined. It has been argued by Apple that the categories of indirect costs, indeterminate costs, and intangible factors have an increasing order of difficulty both in terms of measurement and reducibility to a dollar value. Example items which might be included in one of these categories are: floor space requirements, inventory requirements and value, personnel training requirements, effects on production and inventory control time required, spare parts availability, effects on customer service, quality control costs, etc.

According to a recent article by Frank T. Curtin, Vice-President of Cincinnati Milacron, the indirect, indeterminate, and intangible cost factor areas are of continually increasing importance in the justification of manufacturing systems [15]. He states, "Users and builders (of machine tools) as well must develop new methods (of financial justification) that put dollar values on such things as in-process inventory savings, on lead-time reductions, and on floor space requirements."

Although the quantification of such cost factors which do not readily reduce to a dollar value is not a new problem, this quantification remains a problem. Further, there are problems involved in defining the scope of a manufacturing "system", and in defining levels of mechanization and automation within the manufacturing system. Thus, problems of definition and measurement are inherent and thereby pose difficulties in assessing the system economics. Beyond the economics involved in changing from manual-to mechanized-to automated systems, the ability of the manufacturing system to respond to changes in product mix may be inhibited. This inability to respond, or system inflexibility, is a risk factor that should not be ignored in this decision process.

While the issues addressed above are well known, they have not been resolved explictly. Thus, further research on the economics of automation and conversion seems warranted.

Concluding Remarks

Production control can be ideally exercised only when the various manufacturing system decision issues categorized in Table I are addressed and resolved as an integrated whole. The obvious barriers to accomplishing such an ideal are many, very difficult, and expensive to overcome. However, research in the general area of integrated manufacturing systems, both past and current research, is clarifying the dependent nature of the planning, design, and control decision issues in a manufacturing facility. Further, this research is developing models and solution techniques which hold the promise of ultimately capturing the dependent relationships and optimally resolving the multiple, and interactive planning, design, and control decision issues.

The prospect of substantially increasing manufacturing productivity through integrated manufacturing systems will no doubt stimulate increased efforts in this regard in the near-term future.

References

[1] Apple, J. M. Material Handling Systems Design, The Ronald Press Company, New York (1972).

[2] Armarego, E. J. A. and Brown, R. H. The Machining of Metals, Prentice-Hall, Inc. Englewood Cliffs, N.J. (1969).

[3] Arndt, G. "A Graphic Investigation of the Complete Range of Tool Life Exponents", Microtecnic, Vol. 26, No. 6 (August, 1972).

[4] Bartlett, T. E. "Determining Optimal Machine Configurations for Multistage Machining Processes", Production and Inventory Management, Vol. 8, No. 1 (1967).

[5] Beightler, C. and Phillips, D. T. Geometric Programming, John Wiley, New York (1976).

[6] Birk, J. R. and Kelley, R. B. "General Methods to Enable Robots with Vision to Acquire, Orient, and Transport Workpieces", Proceedings, Sixth NSF Grantees' Conference on Production Research and Technology, West Lafayette, Indiana (September, 1978).

[7] Boothroyd, G., Poli, C. R. and Murch, L. E. "Group Technology Applied to the Automatic Handling of Small Parts", Proceedings, Fifth NSF Grantees' Conference on Production Research and Technology, Cambridge, Massachusetts (September, 1977).

[8] Boothroyd, G. and Rusek, P. "Maximum Rate of Profit Criteria in Machining", ASME Publication, Paper No. 75WA/0rid-22 (January, 1976).

[9] Boothroyd, Geoffrey Fundamental.a of Metal Machining and Machine Tools, McGraw Hill, Inc. (1975) .

[10] Bourke, K. W. "A Survey of Manufacturing Systems", Small Systems World (August, 1978).

[11] Buzacott. J. A. and Hanifin. L. E. "Transfer Line Design and Analysis - An Overview", Proceedings, 1978 Fall AIIE Conference, Atlanta, Georgia (December, 1978).

[12] "Can You Computerize Equipment Selection?", Modern Materials Handling (November, 1966).

[13] Colwell, L. V. "Tracking Cutting Conditions by Computer", SME Technical Paper No. MS75-171 (1975) .

[14] Cook, N., Gossard, D., Bilbrey, M., Horev, Y., Melville. R. and Rumsey. S. "Design and Analysis of Computerized Manufacturing Systems for Small Parts with Emphasis on Non Palletized Parts of Rotation", Proceedings, Sixth NSF Grantees' Conference on Production Research and Technology, West Lafayette, Indiana (September, 1978).

[15] Curtin, F. T. "Manufacturing Systems Moving 'Stage Center' in Dramatic Search for Better Productivity", N/C CommLine (January/February, 1979) .

[16] Davis, R. P. "Determining Optimum Operating Characteristics for a Continuous Processing Machine Center", Int. J. Prod. Res., Vol. 16, No. 5 (1978).

[17] Davis, R. P. and Miller, D. M. "A Model for Determining Machine Requirements in a Multi-stage Manufacturing System with Discretely Distributed Demand", J. App. Math. Mod., Vol. 2, No. 2 (1978).

[18] Davis, R. P. and Miller, D. M. "Analysis of the Machine Requirements Problem Through A Parametric Markovian Model", SME Technical Paper - to appear (1979).

[19] Davis, R. P., Wysk, R. A., Agee, M. H. and Kimbler, D. L. "Optimizing Machining Parameters in a Framework for Adaptive Computer Control", Second National Conference on Computers and Industrial Engineering (March, 1979).

[20] Davis, R. P., Wysk, R. A. and Kimbler, D. L. "A Tool Change Scheduling Model for Machining Centers", J. App. Math. Mod. - to appear (1979).

[21] Ermer, D. S. "A Bayesian Model of Machining Economics for Optimization by Adaptive Control", Journal of Engineering for Industry (August, 1970).

[22] Gershwin, S. B., Athans, M. and Ward, J. E. "Progress in Flexible Automation and Materials Handling Research, 1978", Proceedings, Sixth NSF Grantees' Conference on Production Research and Technology, West Lafayette, Indiana (September, 1978).

[23] Groover, M. P. "Adaptive Control and Adaptive Control Machining", MAPEC, Purdue University (1977).

[24] Groover, M. P. "A Definition and Survey of Adaptive Control Machining", SME Technical Paper No. MS70-561 (1970).

[25] Harrington, J., Jr. Computer Integrated Manufacturing, Industrial Press, Inc., New York, New York (1973).

[26] Hati, S. K. and Rao, S. S. "Determination of Optimal Machining Conditions - Deterministic and Probabilistic Approaches", Journal of Engineering for Industry, Paper No. 75-Prod.-K (1975).

[27] Hayes, G. M. "A Generalized Machine Requirements Planning Algorithm for Serial Flow Machining Systems", Unpublished Masters Thesis, Virginia Polytechnic Institute and State University (1978).

[28] Lenz, J. E. and Talavage, J. J. "General Computerized Manufacturing Systems Simulator", Report No. 7, CMS Project, School of Industrial Engineering, Purdue University, West Lafayette, Indiana (August, 1977).

[29] Link, C. H. "CAM-I Process Planning Program, 1976", CAM-I Special Projects, PR-75-ASPP-01 (1976).

[30] Link, C. H. "CAPP-CAM-I Automated Process Planning System", MN/CAM - The New Industrial Revolution (1976).

[31] Marley, T. C. "Adaptive Control - The Logical Next Step in Machine Toll Control", ASTME Technical Paper No. MS68-812 (1968).

[32] Maxwell, W. L. and Wilson, R. C. "Analysis of Dynamic Material Handling Systems by Network Flow", Working Paper No. 4, Manufacturing Flow Research Project, Department of Industrial and Operations Engineering, The University of Michigan, Ann Arbor, Michigan (March, 1978).

[33] Miller, D. M. and Davis, R. P. "The Machine Requirements Problem", Int. J. Prod. Res., Vol. 15, No. 2 (1977).

[34] Miller, D. M. and Davis, R. P. "A Dynamic Resource Allocation Model for a Machine Requirements Problem", AIIE Transactions, Vol. 10, No. 3 (1978).

[35] Moore, J. M. "Computer Aided Facilities Design: An International Survey", The International Journal of Production Research, Vol. 12, No. 1 (January, 1976).

[36] Morris, W. T. "Facilities Planning", Journal of Industrial Engineering, Vol. 9, No. 5 (1958).

[37] Morris, W. T. Analysis for Materials Handling Management, Richard D. Irwin, Inc., Illinois (1962).

[38] Nof, Y. and Wilson, R. C. "INDECS: General Conveyorized Facilities Description and Simulation", Proceedings, Winter Simulation Conference (December, 1976).

[39] Phillips, D. T., Handwerker, M., Piumsomboon, P. and Sathaye, S. "GEMS: A Generalized Manufacturing Simulator", Proceedings, Sixth NSF Grantees' Conference on Production Research and Technology, West Lafayette, Indiana (September, 1978).

[40] Pritsker, A. A. B. GASP IV Simulation Language, John Wiley and Sons, Inc., New York (1974).

[41] Pritsker, A. A. B. Modeling with QGERT, John Wiley and Sons, Inc., New York (1977).

[42] "The Push to Get More from Men and Machines", Business Week (September, 1972).

[43] Reasor, R. R., Davis, R. P. and Miller, D. M. "Determination of Machine Requirements Via Simulation", Proceedings: 1977 Winter Simulation Conference (December, 1977).

[44] Reed, R. "A Probabilistic Model for Machine Determination", Proc. 17th Annual AIIE Institute Conference, New York (1966).

[45] Rowan, M. J. "Where Systems Planners Still Play Second Fiddle", Editorial Comments, Modern Materials Handling (October, 1978).

[46] Runner, J. A. and Leimkuhler, F. F. "CAMSAM: A Simulation Analysis Model for Computerized Manufacturing Systems", Report No. 12, CMS Project, School of Industrial Engineering, Purdue University, West Lafayette, Indiana (December, 1978).

[47] Sandford, J. E. "DNC Lines Link Cutting to a New Future", Iron Age (October, 1972).

[48] Solberg, J. J. "CAN-Q User's Guide (FORTRAN Version)", Working Paper, School of Industrial Engineering, Purdue University, West Lafayette, Indiana (July, 1978).

[49] Steffy, W. Economics of Machine Tool Procurement, Society of Manufacturing Engineers, Dearborn, Michigan.

[50] Valek, R. J. and Russo, F. A. "Performance Measurement Techniques for Adaptive Process Control", Technical Report AFML-TR-68-265 U.S. Air Force Materials Laboratory (September, 1968).

[51] Wandmaeker, R. R. "CAM-I and the Process Planning Project", Proceedings, Second NSF Grantees' Conference (January, 1975).

[52] Williams, V. A. "DNC for Flexibility", Production (September, 1974).

[53] Wilson, R. C. "Integrated Description and Evaluation of Conveyorized Systems", Working Paper No. 1, Manufacturing Flow Research Project, Department of Industrial and Operations Engineering, The University of Michigan, Ann Arbor, Michigan (September, 1977).

[54] Wilson, R. C., et al. "Modeling and Analysis of Material Handling Systems", Proceedings Sixth NSF Grantees' Conference on Production Research and Technology, West Lafayette, Indiana (September, 1978).

[55] Wysk, R. A., Kimbler, D. L. and Davis, R. P. "Simulation Analysis of the Feasibility of Adaptive Controlled Machining Processes", Second National Conference on Computers and Industrial Engineering (March, 1979).

[56] Wysk, R. A., Miller, D. M. and Davis, R. P. "Integrated Process Selection and Machine Requirements Planning", Proceedings: 1977 Systems Engineering Conference (November, 1977).

[57] Wysk, R. A. "An Automated Process Planning and Selection Program, APPAS", Ph.D. Thesis, Purdue University, West Lafayette, Indiana (1977).

Quality Circles: Japanese success story

A look at how Quality Circles operate using an example in an electronics firm, shows how defects can be minimized when workers discover and attack the problems.

STEPHAN KONZ
Kansas State University, Manhattan, KS

Thirty years ago a made in Japan label brought up the image of cheap, low quality, plastic products. Now the image has changed to quality, high technology products. How did they do it? one collection of their tech. niques.is known as Quality Circles.

Table 1. Highlights of the QC Circle movement.

Date	Event
1962	QCfor the Foreman begins its quarterly publication. First QC Circle registered with JUSE. First foreman conference.
1963	First QC Circle conference.
1964	QC for the Foreman becomes monthly. Regional chapters organized.
1965	Foreman QC award established.
1967	JUSE starts basic QC course for foremen.
1970	Fundamentals of QC Circ[e published. QC correspondence course starts.
1971	First QC Circle cruising seminar. 200th QC Circle conference held. First ail-Japan competition conference held.
1972	50,000 registered ,QC Circles.
1973	300th QC Circle conference held. 60,000 registered Circles.
1974	400th QC Circle conference held.
1975	70,000 registered Circles. 500th QC Circle conference held.

The Japanese received training in quality control from Americans ('Juran and Deming) during the 1950's. From them, they learned that quality is built in, not inspected in; quality requires implementing many small details; and some specific technical techniques (such as control charts) were available.

In the USA, the approach was to teach the technical staff the techniques–either during university training or during short courses. The technical staff then was expected to use the techniques and secure the cooperation of management and the workers in getting improvements implemented. The Japanese used a different approach. They trained the workers themselves in the techniques—as well as management and the technical staff. The concept was that the workers themselves would use the techniques. This would reduce communication problems, reduce resistance to change problems, and permit the people most familiar with the problems to do the work. Then, after a team of workers had selected, analyzed, and solved a problem, they would present their proposed solution to the technical staff and management. The approach, called Quality Circles, emphasized thousands of people working on problems rather than an elite group of engineers and managers telling the thousands–i.e., "for quality, use quantity." It was necessary to develop training programs to make the techniques understandable to the typical worker but this was done.

Table I shows some highlights of the QC Circle movement.[1] The start was in May 1963. As of December 1978, the Union of Japanese Scientists and Engineers (JUSE) had

Continued on P. 26

A QC Circle project

The example[3] shows how Miss F. Hashimoto's QC Circle team at Matsushita Electric analyzed switches used for volume control on stereos. Step one was to select the project. Among the defects from the assembly line, the largest percentage was attributed to the volume switch. After consolation with management, the Circle decided to study switch defects.

Step two was to analyze present conditions. Figure 1 shows their Pareto diagram for defects over a 3-month period. The Y axis is percent defective. The X axis is a series of bars, arranged in descending magnitude, of the various causes, They cross-hatched the major cause for emphasis. Then they plotted cumulative defects (line with dots). "Rotation" was 70T0 of the defects. The Pareto distribution, also called the insignificant many and the mighty few, encourages "fighting giants" so switch rotation was picked as the project.

Figure 2 shows an analysis of the causes of rotation defects: 87% were uneven rotation. Then the Circle members used a cause-effect, or fish diagram, Figure 3, to organize the problem and improve communication. Development of the diagram required a series of Circle meetings. The fish head contains the goals, the major bones the major causes, and the minor bones the contributors to the major causes. With Figure 3 as a guide, they collected defect data from the in-process inspectors, sorted it by cause, and developed Figure 4.

The third step was to establish goals. At their next Circle meeting they established three goals: Reduce rotation defect rate from 1.3% (as of January 1965) to 0.5% by December 1965, while introducing a more stable control system. Develop an overall Circle implementation plan, Figure 5. Selectively attack for improvement the problems while using the Pareto chart order.

The fourth' step was to promote control activities. One activity was an np chart, Figure 6. For their production, a sample (n = 400) taken every hour was appropriate. When an out-of-control condition developed (point beyond control limits), the circle had a meeting. Depending upon the nature of the problem,

001 9-8234/79/1 000-0024$02.00/0

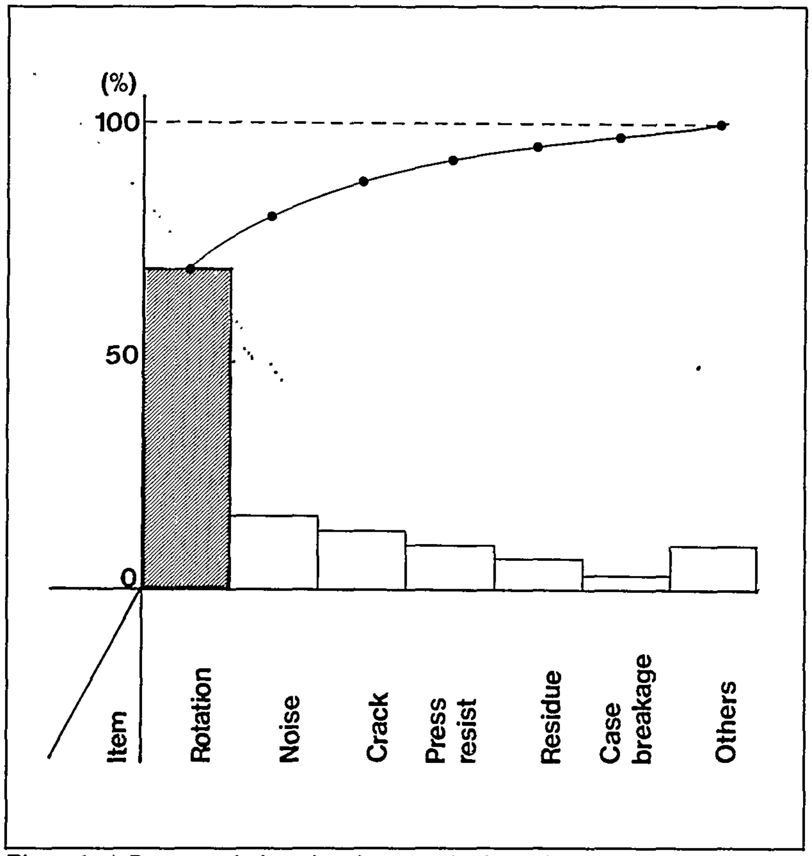


Figure 1. A Pareto analysis, using three months data, showed that switch rotation accounted for 70% of the defects. Thus it was selected for further analysis.

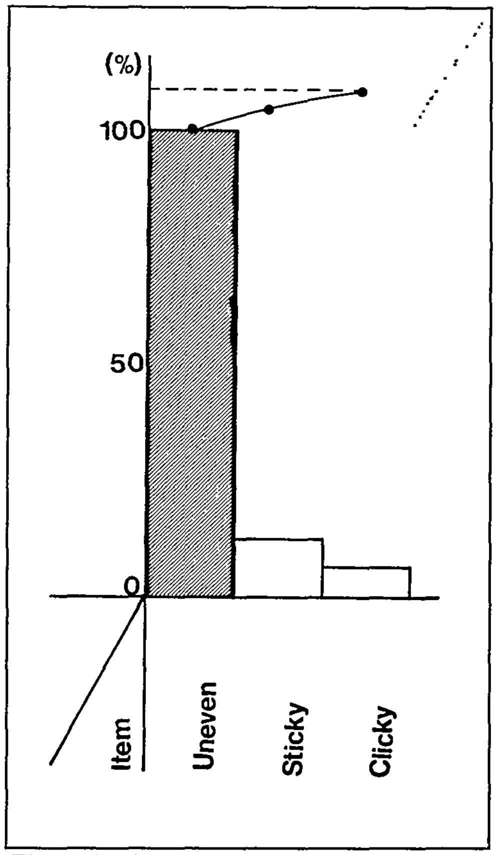


Figure 2. Another Pareto analysis, analyzing rotation defects by phenomena, showed that 87% of the problems were uneven rotation.

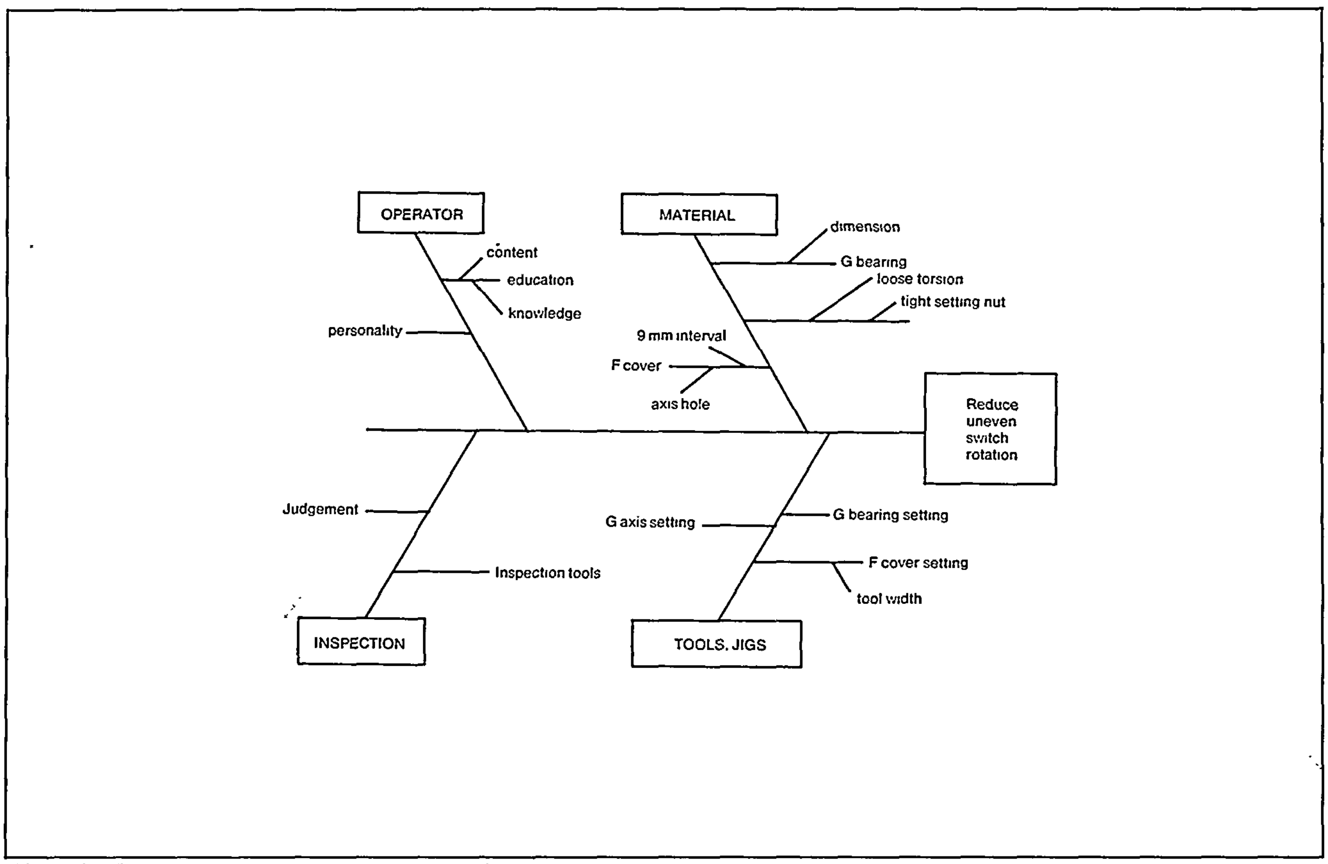


Figure 3. Uneven rotation errors were the target of a cause-effect diagram. The fish head is the goal, major bones are the major categories, and minor bones are the sub-divisions of the major categories.

they either determined the problem cause or a measure to prevent recurrence of the problem. In order to control common deficiencies in previous operations, check lists were developed for critical control points. The operators used these check lists to check their own work. After improved procedures were put into practice and found workable, the standard procedure was revised to insure continued use of the new method, and sample size was changed from 400 to 1600.

As a result of these activities the defect rate was reduced from 1.3% to 0.3% for an annual saving of 400,000 Y (about $1000 at the exchange rate in 1965). In her paper, Miss Hashimoto concluded that although they had achieved their goal they had not completely eliminated the problems. They were determined to continue improvement to achieve a still better result. In addition, she commented that as an inexperienced Circle leader she had not worked enough with people from other departments.

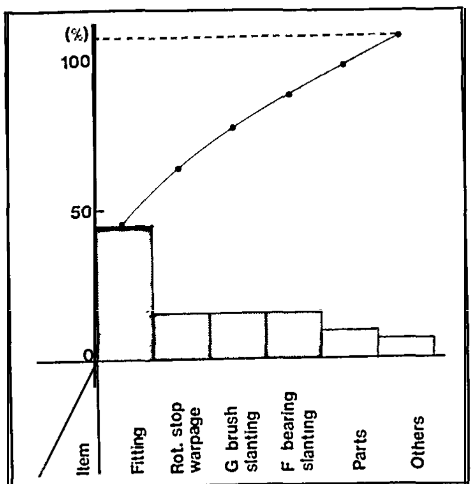


Figure 4. Using the fish diagram in consultation with the in-process inspectors, the Circle developed a new Pareto diagram of causes of uneven rotation.

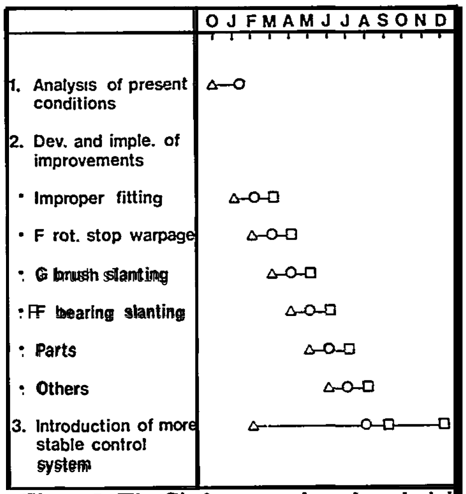


Figure 5. The Circle sets goals and a schedule at their next meeting.

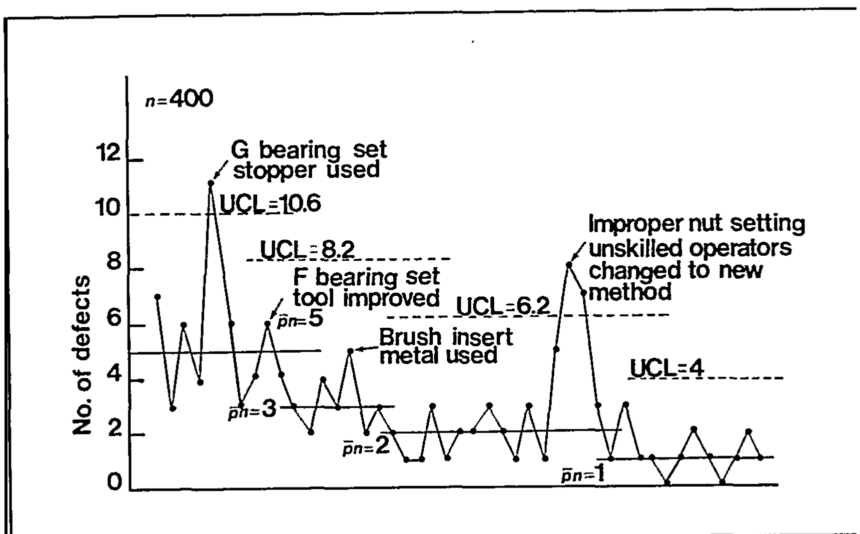


Figure 6. An np chart helped identify when defects occurred so their causes could b eliminated. The first control limits describe the original process. The second set of limit describes the results after the second and third Circle meetings. The third set describe results after the fourth, fifth, sixth meetings, and the fourth set after the seventh meeting

14,800 registered Circles with 303,000 members. They estimate about 15% of all Circles are registered.[2] For reference, in 1978, AIIE membership was 25,000 (plus 6000 student members); the American Society for Quality Control membership was 29,000. Japan has a population of 114 million which is about 53% of the USA population of 217 million.

Circles range from 3 to 25 members, but 10 or less seem to work best; membership is voluntary. Meetings typically are once a month but may be as often as once a week. Sometimes they are outside working hours and sometimes within. When outside normal hours the members usually are paid but not always. Rewards for the Circle members are not financial but they receive praise, publicity, and self-satisfaction. Projects are nominated by the workers about half the time and by the staff half the time. Projects are selected after discussion within the Circle followed by agreement between the Chricle leader and the management. Topics include not only direct quality problems but also housekeeping, safety, work simplification, work schedules, etc. Training is at several levels: workers, Circle leaders, supervisors, and management.

Comments on example project

A number of comments can be made about the example project. First, this was a small project with a $1000-per-year saving. Yet a considerable amount of work was necessary to achieve the saving. In all of the many examples of Quality Circles, I have not seen return on investment reported. The number reported, typically, is annual savings or percent defects. This implies that the engineering cost of making the change is not considered to be worth reporting. However, this engineering cost may be quite low as it is done during normal work time with no decrease in work output, and meetings held outside work hours are charged to training or general quality costs.

Second, the Circle members used techniques that, by American standards, are sophisticated. Pareto diagrams, cause-effect diagrams, and np control charts are not even known to

many American engineers-much less used. The key here is management's emphasis on training members in the use of these techniques and encouraging their use.

Third, quality problems were not considered to be motivational problems but were considered to be technical problems. Improvements were use of modified hand tools, modified assembly procedures, modified operator training, and the use of check lists by the operators. This allowed a systematic, analytical approach instead of a personal attack on specific individuals.

Fourth, many problems are communication problems. Fukuda of Sumitomo Electric[4] summarized the results of 87 groups at his firm as shown in Table II. Figure 7 is a modified version of one of his figures showing that information must be known to both the operator and the technical staff in order to be practiced. In fact, knowledge alone is not sufficient as both groups must want to apply the knowledge. Fukuda summarized the figure in the saying "defense before offense". In "defense", try to move from category B, C, and D to A. Defensive examples are to put warnings and suggestions into easily readable visible form, to clearly define standard operations, and to develop tools enabling less effort yet more skill to be put forth. Only when you are "farming as well as you know how" do you take the offense and make changes- in equipment and manufacturing conditions.

Matsushita has demonstrated the Japanese approach to quality can be applied in the USA. Juran[5] reports that Motorola TV sets had 1.5 to 1.8 defects discovered at the factory per set packed before Matsushita took over. Now, under the brand name Quasar, the defect rate, with the same employees, is 0.03 to 0.04. The rate in Japan is 0.005/set!

References

[1] Amsden, D. and Amsden, R., Ed.; QC Circles: Abdications, Tools and Theory, American Society for Quality Control, Milwaukee, WI, 1976, p. 31.

[2] Personal communication, Union of Japanese Scientists and Engineers, 5-10-11, Tokyo, 19 Dec. 1978.

[3] Ishikawa, K. Ed.; QC Circle A ctiuitit-s (in English), 66-69, Union of Japanese Scientists and Engineers, Tokyo, 1968.

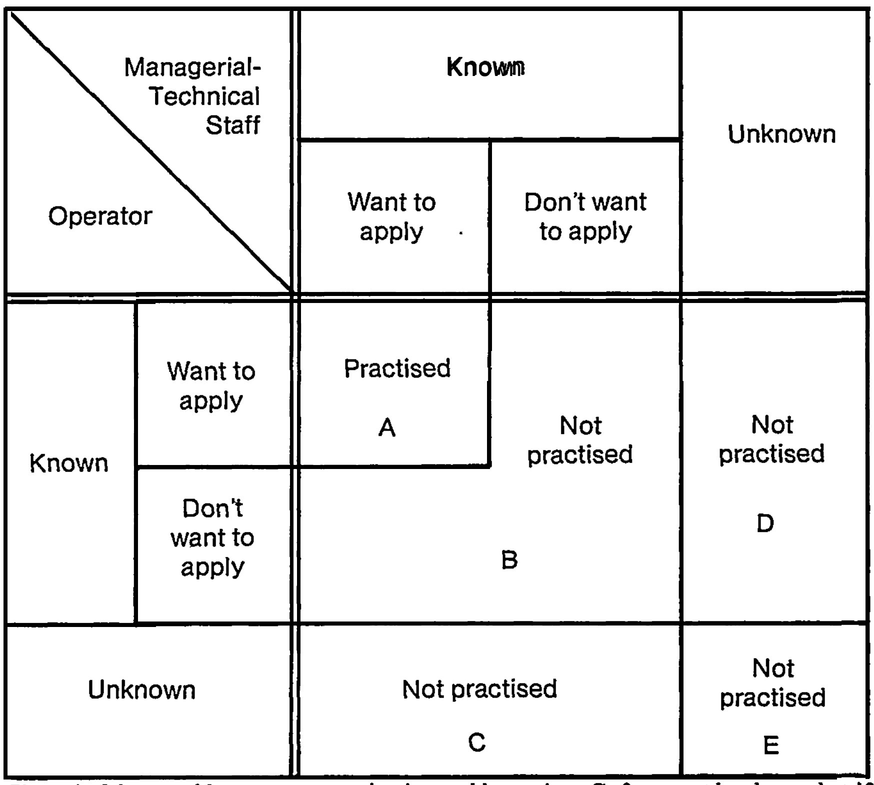
[4] Fukuda, R.; "The Reduction of Quality Defects by the Application of a Cause and Effect Diagram with the Addition of Cards;" 117-13 1.in Production and Industnal Systems (Proceedings of the Fourth Int'1. Conference on Production Research); Muramatsu, R. and Dudley, N., Ed., Taylor and Francis, London, 1978,

[5] Juran, J.; Japanese and Western Quality–A Contrast"; Quality *Progress,* Vol. 11, 12, 1978.

Table II: Various types of countermeasures found effective by QC Circles at Sumitomo.

	Type of result (%)			
	Limited		Considerable	
Countermeasure type	slow	Quick	slow	Quick
Warnings and suggestions put into easily readable visual form–defensive.	41	25	57	68
Clearly defining standard operations—defensive.	24	35	24	53
Developing tools enabling less effort yet more skill to be put forth–defensive.	12	5	37	32
Making improvement in equipment—offensive.	5	5	30	12
Making changes in manufacturing conditions—offensive.	o	5	20	5

Quick = within 3 months; slow = over 3 months. Limited = reduction of defects of less than 40%; considerable = over 40%.



igure 7. Many problems are communication problems. Area C, for example, shows that if nformation is known to the technical-managerial staff but not to the operator, the echnique is not practiced.

ENGINEERING ECONOMY STUDIES IN AN INFLATIONARY ENVIRONMENT

William G. Sullivan, P.E.
Professor, Industrial Engineering
The University of Tennessee
Knoxville, Tennessee 37916

James A. Bontadelli, P.E.
Manager, Industrial Engineering
Tennessee Valley Authority
Knoxville, Tennessee 37902

ABSTRACT

This paper presents and explaina two related procedures for dealing with inflation in engineering economic evaluations. One procedure is tailored to cost estimates that are made in terms of actual (current) dollara. The second procedure requires that cost estimates be prepared in real (constant) dollars. Private induatriea in the U.S. tend to prefer the firat procedure, while many government agencies require that economic evaluations be performed with real dollar estimatea. Both procedures, if properly carried out, result in identical selection between alternativea. Furthermore, it is possible to demonstrate the equivalence of numerical quantities of one procedure with corresponding quantities computed by the other. Two example problems are presented. Example 1 establishes some baaic principles regarding the two procedures (i.e., actual versus real dollar analysis), and Example 2 shows that these same principles apply when dealing with multiple inflation rates.

INTRODUCTION

Problems associated with double-digit inflation are constantly mentioned by the news media. Many economists unequivocally atate that inflation is our NUMBER ONE PROBLEM. Each time we make a purchase, we are painfully reminded of Webster's definition of inflation: "A diaproportionate and relatively aharp and sudden increase in the quantity of money or credit, or both, relative to gooda available for purchaae (14)." Inflation alwaya produces a rise in the price level. Alternatively, inflation causes the value of the monetary unit being used to decrease with the passage of time.

Moat government indicators of inflation (e.g., the consumer price index) point to an inflation rate in 1979 that exceeds 12 percent. If the effects of inflation are not included in engineering economic evaluations, erroneous choices between competing alternatives can be made. At a time when the most productive use of capital is so important, it seems foolish to ignore inflation and run the risk of losing competitive position because of ignorance or indifference in this regard. Omitting inflation in engineering economy studies ia equivalent to asauming a monetary unit of constant value. This is clearly out of tune with the real-world business environment.

ACTUAL DOLLAR VERSUS REAL DOLLAR ANALYSES

Given that inflation is to be considered, one might ask "How can I do this in a way that is technically **correct and at the same time allows me to communi-**cate my results to management?" Many writera in the field of engineering economics recommend an analyais procedure that clearly lays out all cash flow and depreciation quantities in tabular form (7, 8, 9, 11, 12, 13). The manner in which these quantities are estimated then determines the procedure that the subsequent analysis involves. Generally speaking, the elements of a future cash flow can be estimated in actual (current) dollars, which explicitly takes inflation into account, or in real (constant) dollars that excludes inflation. This applies to depreciation as well.

In many instances, an "actual dollar" analysis or a "real dollar" analysis will be specifically required by an organization. Most government-aponaored evaluations are made in terms of real dollars in accordance with (6). A primary reaaon for this approach stems from the fact that most economy studies in the public sector do not involve income tax considerations and thus do not explicitly take depreciation into account. On the other hand, private industry tends to favor engineering economy studies in actual dollars because after-tax results are a primary consideration and are affected by depreciation.

As mentioned previously, the actual dollar procedure works with future cash flows and depreciation write-offs that are expected to be experienced in year j **($0 \le j \le N$) of the study period. Because actual-**dollar cash flows are estimated to account for inflation that occurs from year O (the base year of the analysis) to year j, they must be discounted at a rate which includes an allowance for the annual general inflation rate (f) plus a monetary (real) rate of return (i_m) to the organization. (All factors that use these rates in this paper are in decimal form.) This combined discount rate is determined as follows.

$$1 + i_c = (1 + i_m)(1 + f); \text{ or} \qquad (1)$$

$$i_c = i_m + f + i_m(f) \qquad (2)$$

1. In this paper depreciation is referred to as one of the cash flow elements even though it is a non-cash flow item which affects the after-tax-cash-flow computations only.

Equation (2) is interpreted in further detail in Appendix A.

When a discount rate is specified as 24 percent, for example, it must be made clear whether this is a combined or a monetary rate. Such a high figure would imply that it is a combined rate but this should be carefully verified. If a company specifies an 24 percent rate of return on its investment but adopts this figure in view of an anticipated 10 percent annual general inflation rate, then the 24 percent is a combined rate and their required monetary (i.e., real) return is only 12.7 percent.

This distinction is important because a combined interest rate is used for discounting purposes in the actual dollar procedure and a monetary (real) interest rate is utilized in the real dollar procedure. When one of the discount rates is determined, it is a simple matter to calculate i_m (or i_c) if f has been projected. Further discussion and illustration of these concepts are given in reference (4).

Because of the existence of these two different and widely accepted procedures for dealing with inflation, the remainder of this paper is concerned with demonstrating the basic principles of each analysis procedure in after-tax engineering economy studies and showing that they are-equivalent. This is accomplished first for a rather simple problem, followed then by a more complex problem involving multiple inflation (escalation)[2] rates.

EXAMPLE 1

To illustrate the actual dollar and real dollar analysia procedures for incorporating inflation into engineering economy studies, the first example problem concerns the replacement of an existing piece of equipment. The two alternatives being investigated are (1) purchasing the equipment or (2) leasing the equipment. Assume that the company must' replace this equipment because it is vital to comply with certain Federal and State safety requirements and the following estimates and assumptions apply:

1. The study period is five years and the estimated useful life of either alternative also is five years. Straight-line depreciation is used with an estimated zero net salvage value at the end of the useful life for the purchased equipment. The effective incremental income tax rate (t_e) is 50 percent. Also, a 10 percent investment tax credit can be taken. All capital gains are taxed at 50 percent of the gain.

2. The following factors are used:

   a. Monetary (real) discount rate (i_m) is 10 percent.

   b. Annual general inflation (f) is 8 percent.

   c. Combined discount rate (i_c) is 18.8 percent (i.e., $i_c = 0.10 + 0.08 + 0.10(0.08) = 0.188$ or 18.8 percent).

3. Annual savings, operating costs, maintenance costs, and the terminal market value are known with certainty and respond to inflation. In the case of leasing the equipment, the yearly lease payment does not grow with inflation. When purchasing the equipment the depreciation writeoffs do not respond to inflation.

4. Annual cash flow elements:

	Purchase Equipment	Lease Equipment
Savings	\$ 5,000	\$ 5,000
Operating Costs	-2,000	-2,000
Maintenance	-1,000	(Included in lease contract)
Lease Fee		-6,000 (Payable at end of year)

   All the annual cash flow elements have been estimated in real dollars (year O).

5. Investment costs:

Purchase Equipment	Lease Equipment
Initial cost = \$20,000	Deposit = \$1,500, refundable at end of 5 years
Market value = \$1,500 at end of year 5 (in real dollars)	

6. The analysis is performed after taxes and a general inflation rate (f) of 8 percent is estimated to apply to all cash flow elements that respond to inflation.

Based on the above information, we want to determine whether the company should buy or leaae the equipment. An after-tax study is now performed in terms of actual dollars and real dollars, and the equivalence of both procedures is demonstrated.

Actual Dollar Analysis

Because annual savings, operating costs, and maintenance coats are all responsive to inflation, the required adjustments to these cash flows are made in Column C of Tables 1 and 2 using the following relationship:

2. In Example 1 the terms inflation and escalation can be used interchangeably. However, in Example 2 it is necessary to define a difference between them.

TABLE 1

EXAMPLE 1: PURCHASE EQUIPMENT ALTERNATIVE--ACTUAL DOLLAR ANALYSIS

Year	(A) BTCF Real Dollars	(B) Inflation Factor $(1 + f)^j$	(C) BTCF Actual Dollars (A · B)	(D) Depreciation	(E) Taxable Income (C + D)	(F) Income Taxes $-t_e \cdot$ (E)	(G) ATCF[3] Actual Dollars (C + F)
0	-20,000	---	-20,000	---	---	2,000[2]	-18,000
1	2,000[1]	1.080	2,160	-4,000	-1,840	920	3,080
2	2,000	1.166	2,332	-4,000	-1,668	834	3,166
3	2,000	1.260	2,520	-4,000	-1,480	740	3,260
4	2,000	1.360	2,720	-4,000	-1,280	640	3,360
5	2,000	1.469	2,938	-4,000	-1,060	531	3,469
5	1,500	1.469	2,204	---	2,204	-1,102	1,102

1. \$5,000 (annual savings) - \$2,000 - \$1,000 = \$2,000 (BTCF--real dollars)
2. Investment tax credit
3. PW(18.8 percent) = -\$7,601

TABLE 2

EXAMPLE 1: LEASE EQUIPMENT ALTERNATIVE--ACTUAL DOLLAR ANALYSIS

Year	(A) BTCF Real Dollars	(B) Inflation Factor $(1 + f)^j$	(C) BTCF Actual Dollars (A · B)	(D) Lease Payments	(E) Taxable Income (C + D)	(F) Income Taxes $-t_e \cdot$ (E)	(G) ATCF[2] Actual Dollars (C + D + F)
0	-1,500	---	-1,500	---	---	---	-1,500
1	3,000[1]	1.080	3,240	-6,000	-2,760	1,380	-1,380
2	3,000	1.166	3,498	-6,000	-2,502	1,251	-1,251
3	3,000	1.260	3,780	-6,000	-2,220	1,110	-1,110
4	3,000	1.360	4,080	-6,000	-1,920	960	-960
5	3,000	1.469	4,407	-6,000	-1,593	796.5	-796.5
5	1,500	---	1,500	---	---	---	1,500

1. \$5,000 (annual savings) - \$2,000 = \$3,000 (BTCF--real dollars)
2. PW(18.8 percent) = -\$4,395

$$F_j\text{(Actual Dollars in Year j)} = F_0^c(1 + f)^j; \qquad (3)$$
$$\text{Where } F_0^c = \text{Real Dollars in Year 0}$$

The inflated before-tax cash flow is then combined with the remaining elements in Tables 1 and 2 that do not respond to inflation (lease payments and depreciation). The column operations required to determine the after-tax-cash-flows (ATCF) are indicated in the tables. The ATCF now indicates the effects of inflation in actual dollars. To determine the present worth of the purchase and the lease alternative, the ATCF column is discounted at the combined discount rate. At this rate (18.8 percent) the present worth for the purchase alternative is -$7,601 and for the lease alternative it is -$4,395.

A basic principle here is that combined discount rates are used in actual dollar analyses. From Tables 1 and 2 it is apparent that the lease equipment alternative is less expensive and should be the recommended choice. (Recall that this is a project that must be undertaken.)

As a point of interest, if the analysis in Tables 1 and 2 is performed ignoring inflation, the recommended course of action is to purchase the equipment! Assuming a 0 percent inflation rate in this problem leads to an incorrect recommendation.

Real Dollar Analysis

The analysis of these two alternatives is now repeated (Tables 3 and 4) with all cash flow elements expressed in real dollars (base year 0). The column operations required to determine the ATCF in real dollars are indicated. Even though depreciation, lease payments, and deposits are nonresponsive to Lnflation, they are actual dollars and must be deflated to reflect their loss in real value over time. These adjustments are shown in Column C of Tables 3 and 4 where the following relationship is used:

$$F_j^c\text{(Real Dollars in Year j)} = F_j(1 + f)^{-j}; \qquad (4)$$
$$\text{Where } F_j = \text{Actual Dollars in Year j}$$

It is very important to ascertain which quantities respond or do not respond to inflation and then to treat them correctly with the analysis procedure that is being used.

In Tables 3 and 4 the ATCF (in real dollars) is discounted at the monetary interest rate of 10 percent. It should be recalled that monetary rates are utilized for purposes of discounting in real dollar economy studies. Furthermore, it should be observed that the present worth of the "purchase equipment alternative" has the same value in Tables 1 and 3. The same result also occurs for the present worth of the "lease equipment alternative" in Tables 2 and 4. If P equals the present worth of the AT.CF in an actual dollar analysis and Pc equals the present worth in a real dollar analysis, then $P = P^c$ will always hold true if both procedures have been correctly carried out. A more generalized discussion of this result is providedby Baum (l). Further demonstration that $P = P^c$ is given in Example 2 where differential rates of inflation (escalation) are treated.

TABLE 3

EXAMPLE 1: PURCHASE EQUIPMENT ALTERNATIVE--REAL DOLLAR ANALYSIS

Year	(A) BTCF Real Dollars	(B) Depreciation Actual Dollars	(C) Depreciation Real Dollars, $1/(1 + f)^j$	(D) Taxable Income (A + C)	(E) Income Taxes $-t_e \cdot$ (D)	(F) ATCF[2] Real Dollars (A + E)
0	-20,000	---	---	---	2,000	-18,000
1	2,000	-4,000	-3,704	-1,704	852	2,852
2	2,000	-4,000	-3,429	-1,429	714.50	2,714.50
3	2,000	-4,000	-3,175	-1,175	587.50	2,587.50
4	2,000	-4,000	-2,940	- 940	470	2,470
5	2,000	-4,000	-2,722	- 722	361	2,361
5	1,500[1]	---	---	1,500	-750	750[1]

1. The market value was estimated in real dollars
2. PW(10 percent) = -$7,601

TABLE 4

EXAMPLE 1: LEASE EQUIPMENT ALTERNATIVE--REAL DOLLAR ANALYSIS

Year	(A) BTCF Real Dollars	(B) Lease Payments Actual Dollars	(C) Lease Payments Real Dollars (B) $1/(1 + f)^j$	(D) Taxable Income (A + C)	(E) Income Taxes $-t_e \cdot$ (D)	(F) ATCF[2] Real Dollars (A + C + E)
0	-1,500	---	---	---	---	-1,500
1	3,000	-6,000	-5,556	-2,556	1,278	-1,278
2	3,000	-6,000	-5,144	-2,144	1,072	-1,072
3	3,000	-6,000	-4,763	-1,763	881.50	- 881.50
4	3,000	-6,000	-4,410	-1,410	705	- 705
5	3,000	-6,000	-4,084	-1,084	542	- 542
5	1,500[1]	---	---	---	---	1,021[1]

1. The deposit of $1,500 would decline in real value at 8 percent per year for five years
2. PW(10 percent) = -$4,395

EXAMPLE 2

Let us proceed from the simple case (Example 1) to the next level of complexity where some of the cash flow elements involved (labor, material, revenues, etc.) are estimated to escalate or de-escalate differently in the future. For this part of the discussion, some additional terms are defined:

e_k = effective annual escalation rate for cash flow element k

e'_k = differential annual adjustment rate for cash flow element k (actually, as explained later, this differential acts as a basic price adjustment rate and can be negative)

$F_{k,j}$ = estimate for year j in actual dollars for the number of units of cash flow element k projected in year j

$F^c_{k,j}$ = estimate for year j in real dollars for the number of units of cash flow element k projected in year j

$F^c_{k,0}$ = estimate in year 0 in real dollars for the number of units of cash flow element k projected in year j

It should be noted that in year 0 (i.e., when j = 0) all three estimates are the same.

The defined relationship between f, e_k, and e'_k is:

$$1 + e_k = (1 + f)(1 + e'_k);\ \text{or} \tag{5}$$

$$e_k = f + e'_k + f \cdot e'_k;\ \text{and} \tag{6}$$

$$e'_k = (e_k - f)/(1 + f) \tag{7}$$

Thus, as shown in equation 5, the effective annual escalation factor for cash flow element k $(1 + e_k)$ is equal to the general annual inflation factor $(1 + f)$ multiplied by the differential annual adjustment factor for cash flow element k $(1 + e'_k)$. Also, when e_k is equal to f (i.e., the effective annual escalation rate for cash flow element k is equal to the general inflation rate) the differential adjustment rate e'_k is zero (from equation 7) and the effective annual escalation factor for cash flow element k is just $(1 + f)$.

The relationships between $F_{k,j}$, $F^c_{k,j}$, and $F^c_{k,0}$ are:

$$\begin{aligned} F_{k,j} &= F^c_{k,0}(1 + e_k)^j \qquad (8) \\ &= F^c_{k,0}[(1 + f)(1 + e'_k)]^j \\ &= F^c_{k,0}(1 + f)^j(1 + e'_k)^j;\ \text{or} \end{aligned}$$

$$F_{k,j}/(1 + f)^j = F^c_{k,0}(1 + e'_k)^j \tag{9}$$

Also,

$$F_{k,j} = F^c_{k,j}(1 + f)^j;\ \text{or} \tag{10}$$

$$F^c_{k,j} = F_{k,j}/(1 + f)^j \tag{11}$$

And from equations 9 and 11

$$F^c_{k,j} = F^c_{k,0}(1 + e'_k)^j \qquad (12)$$

From the above relationships, the following observations can be made:

1. In equation 8 we have aasumed that the future price per unit in year j (actual dollars) for cash flow element k (e.g., labor) can be estimated by multiplying the unit price in year 0 (real dollars) by the effective annual escalation factor for cash flow element k raised to the j^{th} power. This is analogous to equation 3 where the escalation rate for all cash flow elements was equal to the annual general inflation rate f.

2. In equation 10 the relationship in any future time period (i.e., in year j) between "actual dollars" and "real dollars" (with base year 0) is defined as a function of the annual general inflation factor. This structure defines the annual general inflation rate as the reference inflation rate previously deduced by Baum (2) (which is as he stated "implicit in the idea of two rates of return"--assuming the relationship defined by equation 8). This structure also provides a simple relationship (equation 11) between actual and real dollar cash flow elements including the total cash flow for either the before or after tax situation. This is analogous to equation 4 in Example 1. In addition, this structure provides a realistic definition and explanation for the specific differential adjustment rates which reflect (and estimate over time) the changing prices of the various goods and services in the "marketplace." (Reference equation 12 and observations 3 and 4 below.)

3. When e_k is equal to f (which results in $e'_k = 0$), then $F^c_{k,j} = F^c_{k,0}$. Thus, when the unit price in or cash flow element k is projected to change at the annual general inflation rate, the number of real dollars required in year 0 to purchase one unit of the resource is the same as required in any future year j.

4. However, when e'_k is not equal to zero, the unit price for cash flow element k is projected to change. This differential adjustment rate defined by equation 7 reflects the projected annual percent unit price increase (or decrease) in the "marketplace" of a cash flow element with respect to all other goods and services.

Let us look at how easily different effective rates of escalation as defined above can be handled in a problem. In this situation (Example 2) an initial investment in equipment of $15,000 is being contemplated to increase the output (and revenues) on a product line in a small manufacturing plant. The following additional estimates and assumptions apply:

1. The analysis (or study) period is the next 10 years. Also, the estimated life of the new equipment is 10 years with zero net salvage value at that time. Straight-line depreciation applies. The incremental income tax rate (t_e) is 46 percent (ignore investment tax credit).

2. The following factors have the values indicated:

   a. Monetary (real) discount rate (i_m) is 4 percent.

   b. Annual general inflation factor (f) is 6 percent.

   c. Conbined discount rate (i_c) is 10.24 percent (i.e., i_c=0.04+0.06+ (0.04)(0.06) = 0.1024 or 10.24 percent).

3. Increased <u>revenues</u> are estimated at $11,000 per year in real dollars. Escalation of revenues is estimated based on the annual general inflation rate, i.e., e_r = f = 6 percent.

4. Annual costs:

Cash Flow Element	Annual costs (Year 0 Dollars)	e_k[3] (%)	Escalation Factor $(1 + e_k)$
Material	$F^c_{1,0}$=$1,000	e_1=10.0	1.10
Labor	$F^c_{2,0}$=$2,000	e_2=5.5	1.055
Energy	$F^c_{3,0}$=$2,000	e_3=15.0	1.15
Other Costs	$F^c_{4,0}$=$ 200	e_4=f=6.0	1.06

   In addition to the above costs there is some leased equipment. This equipment can be obtained for the first five years at a rate of $600 per year. However, the contract will be renegotiated at the beginning of the sixth year and escalation is estimated at the annual general inflation rate (f).

Actual Dollar Analysis

With this information let us accomplish an after tax net present worth (NPW) analysis using actual dollars followed by an analysis in real dollars. Recall from Example 1 that the combined discount rate (i_c) is used in actual dollar analyses and the monetary (real) discount rate (i_m) applies to real dollar analyses.

Development of the after-tax-cash-flow (ATCF) in actual dollars is shown in Table 5.

1. Revenues and costs are projected from the real dollar values in year 0 ($F^c_{k,0}$) using compound escalation with the approprrate factor. For example:

   Estimated Material Costs (Year j) = $F^c_{1,0}(1 + e_1)^j$ = $1,000(1.10)^j

---

3. For example, in the construction industry two sources of inflation data are <u>Engineering News Record</u> and <u>Handy Whitman</u>.

TABLE 5

EXAMPLE 2: AFTER-TAX-CASH-FLOW DEVELOPMENT FOR ACTUAL DOLLAR ANALYSIS

Year	Revenues	Initial Investment	Material	Labor	Energy	Other Costs	Lease Equipment	Total Costs (Actual Dollars)	BTCF (Actual Dollars)	Depreciation	Taxable Income	Income Taxes	ATCF[1] (Actual Dollars)
0	--	-15,000	--	--	--	--	--	-15,000	-15,000	--	--	--	-15,000
1	11,660	--	-1,100	-2,110	-2,300	-212	-600	- 6,322	5,338	-1,500	3,838	-1,765	3,572
2	12,360	--	-1,210	-2,226	-2,645	-225	-600	- 6,906	5,454	-1,500	3,954	-1,819	3,635
3	13,101	--	-1,331	-2,348	-3,042	-238	-600	- 7,559	5,542	-1,500	4,042	-1,859	3,683
4	13,887	--	-1,464	-2,478	-3,498	-252	-600	- 8,292	5,595	-1,500	4,095	-1,884	3,711
5	14,720	--	-1,611	-2,614	-4,023	-268	-600	- 9,116	5,604	-1,500	4,104	-1,888	3,716
6	15,604	--	-1,771	-2,758	-4,626	-284	-803	-10,242	5,362	-1,500	3,862	-1,777	3,585
7	16,540	--	-1,949	-2,909	-5,320	-301	-803	-11,282	5,258	-1,500	3,758	-1,729	3,529
8	17,532	--	-2,144	-3,069	-6,118	-319	-803	-12,453	5,079	-1,500	3,579	-1,646	3,433
9	18,584	--	-2,358	-3,238	-7,036	-338	-803	-13,773	4,811	-1,500	3,311	-1,523	3,289
10	19,699	--	-2,594	-3,416	-8,091	-358	-803	-15,262	4,437	-1,500	2,937	-1,351	3,086

1. NPW(10.24 percent) = $6,662

TABLE 6

EXAMPLE 2: AFTER-TAX-CASH-FLOW DEVELOPMENT FOR REAL DOLLAR ANALYSIS

Year	Revenues	Initial Investment	Material	Labor	Energy	Other Costs	Lease Equipment	Total Costs (Real Dollars)	BTCF (Real Dollars)	Depreciation	Taxable Income	Income Taxes	ATCF[1] (Real Dollars)
0	--	-15,000	--	--	--	--	--	-15,000	-15,000	--	--	--	-15,000
1	11,000	--	-1,038	-1,991	-2,170	-200	-566	- 5,965	5,035	-1,415	3,620	-1,665	3,370
2	11,000	--	-1,077	-1,981	-2,354	-200	-534	- 6,146	4,854	-1,335	3,519	-1,619	3,235
3	11,000	--	-1,118	-1,972	-2,554	-200	-504	- 6,348	4,652	-1,259	3,393	-1,561	3,091
4	11,000	--	-1,160	-1,963	-2,771	-200	-475	- 6,569	4,431	-1,188	3,243	-1,492	2,939
5	11,000	--	-1,203	-1,953	-3,006	-200	-448	- 6,810	4,190	-1,121	3,069	-1,412	2,778
6	11,000	--	-1,249	-1,944	-3,261	-200	-566	- 7,220	3,780	-1,057	2,723	-1,253	2,527
7	11,000	--	-1,296	-1,935	-3,538	-200	-534	- 7,503	3,497	- 998	2,499	-1,150	2,347
8	11,000	--	-1,345	-1,926	-3,839	-200	-504	- 7,814	3,186	- 941	2,245	-1,033	2,153
9	11,000	--	-1,396	-1,917	-4,164	-200	-475	- 8,152	2,848	- 888	1,960	- 902	1,946
10	11,000	--	-1,449	-1,908	-4,518	-200	-448	- 8,523	2,477	- 838	1,639	- 754	1,723

1. NPW(4 percent) = $6,660

Estimated Revenues (Year j) = $F^c_{r,0}(1+e_r)^j$ = $\$11,000(1.06)^j$

2. **Equipment lease costs for the first contract period are already in actual dollars. Escalation occurs at the renegotiation point in this example (i.e., $\$600(1.06)^5 = \$803$) and the resulting lease costs for the second contract period are also in actual dollars.**

3. **Depreciation is accounted for in the year indicated** and occurs in actual dollars even though it is based on an initial fixed amount and does not respond to inflation.

The NPW of the actual dollar ATCF in Table 5, using the combined discount rate (i_c = 10.24 percent), is $6,662.

Real Dollar Analysis

Now let us accomplish a NPW analysis in real dollars. The development of the ATCF for the real dollar analysis is shown in Table 6. First, we will calculate the table entries the "hard way," i.e., based on equation 12 (however, this provides an insight into the differential adjustment rate--e'_k--effects).

From equation 12 it is seen that the estimates for year j in real dollars ($F^c_{k,j}$) for the number of units of cash flow element k projected in that year is equal to the estimate in year 0 in real dollars ($F^c_{k,0}$), for the same number of units multiplied by $(1 + e'_k)^j$ for that cash flow element. In the case of material we have:

$$e'_1 = (e_1 - f)/(1 + f) = (.10 - .06)/1.06 = .03774; \text{ and}$$

$$1 + e'_1 = 1.03774; \text{ thus}$$

$$F^c_{1,1} = \$1,000(1.03774) = \$1,038$$

$$F^c_{1,2} = \$1,000(1.03774)^2 = \$1,077$$

$$\vdots$$

$$F^c_{1,10} = \$1,000(1.03774)^{10} = \$1,449$$

For labor (since its effective annual escalation rate is estimated less than the annual general inflation rate) we have:

$$e'_2 = (e_2 - f)/(1 + f) = (0.55 - .06)/1.06 = -.00472; \text{ and}$$

$$1 + e'_2 = (1 - .00472) = 0.99528; \text{ thus}$$

$$F^c_{2,1} = \$2,000(0.99528) = \$1,991$$

$$\vdots$$

$$F^c_{2,10} = \$2,000(0.99528)^{10} = \$1,908$$

Therefore, in this example a unit of labor is becoming less expensive over time in real dollars relative to some of the other goods and services (e.g., material, energy, etc).

For the "other costs" and the revenue cash flow elements the differential annual adjustment rates **(e'_4 and e'_r) are equal to zero (equation 7) since** their annual effective escalation rates are equal to the annual general inflation rate (thus, from equation 12, $F^c_{k,j} = F^c_{k,0}$ **in both cases).**

What about depreciation and leased equipment? In the case of depreciation the effective annual **escalation rate is zero (i.e., $e_d = 0$ and $F^c_{d,0}$ is** set equal to $1,500). Then from equation 3 the differential annual adjustment rate for depreciation is:

$$e'_d = (e_d - f)/(1 + f) = -.06/1.06 = -0.05660; \text{ and}$$

$$1 + e'_d = (1 - .05660) = 0.9434; \text{ thus}$$

$$F^c_{d,1} = \$1,500(0.9434) = \$1,415$$

$$F^c_{d,10} = \$1,500(0.9434)^{10} = \$838$$

For leased equipment during its first contract period (years one through five in this example), the situation normally is analogous to the depreciation case. In this example the effective annual escalation rate during the firet lease period is zero **(i.e., $e_5 = 0$ and $F^c_{5,0}$ is set equal to $600).** Then, from equation 7 the differential annual adjustment -rate for lease costs during the first contract period is:

$$e_5 = (e_5 - f)/(1 + f) = -.06/1.06 = -0.05660; \text{ and}$$

$$1 + e'_5 = (1 - 0.05660) = 0.9434; \text{ thus}$$

$$F^c_{5,1} = \$600(0.9434) = \$566$$

$$F^c_{5,5} = \$600(0.9434)^5 = \$448$$

Since the escalation at the renegotiation point in this example (and reflected in the actual dollar cash flow--see Table 5) is based on the general inflation rate, no differential adjustment rate exists with respect to the second lease period. Therefore, costs during the second contract period, in real dollars, will repeat the lease costs of the first five years.

The NPW of the real dollar ATCF in Table 6, using the monetary (real) **discount rate (i_m = 4.0 percent)** is $6,660. This is the same NPW value (within

rounding error) obtained from the actual dollar analysis in Table 5 using the combined discount rate i_c = 10.24 percent).

Now let us look at the simple relationship between the actual dollar cash flow entries in Table 5 and those for the real dollar analysis in Table 6 (which we just derived the "hard way"). Specifically, every real dollar cash flow entry in Table 6 is equal to the same entry in Table 5 divided by $(1 + f)^j$. Therefore, we could have developed the real dollar cash flow entries ($F^c_{k,j}$) in Table 6, or just the total ATCF portion, the "easy way" from the actual dollar entries in Table 5 by dividing the corresponding entries ($F_{k,j}$) by $(1 + f)^j$ as previously derived in equation 11.

However, we can console ourselves over accomplishing the real dollar analysis the "hard way" initially since the process clearly illustrates the effects of the differential annual adjustment rates. Particularly, the reflection by these adjustment rates of the annual percent unit price increase (or decrease) over time in the "marketplace" of the various goods and services.

THE NEXT LEVEL OF COMPLEXITY

In Example 1 escalation occurred uniformly at the general inflation rate (f) for all cash flow elements to which it applied. Then, in Example 2, differential escalation rates are introduced; that is, some of the cash flow elements are estimated to escalate or de-escalate differently in the future. The next level of complexity involves differential escalation rates (as introduced in Example 2) but these rates may vary over time. That is, the analysis period is divided into two or more time segments in which some changes occur in the estimated rates.

At this level of complexity (which is the limit for most practical applications), the analysis would proceed as in Example 2 except: (1) for each period (time segment) in which the estimate of the general inflation factor (f) changes a different combined discount rate (i_c) is calculated and used within that time period, and (2) the differential annual adjustment rate (e'_k) is recalculated for any cash flow element affected by the changes and used for the time period involved. Again, as in Examples 1 and 2, the results of an actual dollar analysis and a real dollar analysis are equivalent.

APPENDIX A

Previously it was stated that the combined discount rate (i_c) is used in actual dollar analyses and determined by the following relationship:

$$(1 + i_c) = (1 + i_m)(1 + f); \text{ or}$$

$$i_c = i_m + f + i_m(f)$$

The rationale behind the above formula for i_c is summarized in this appendix in terms of a simple example.

If a corporation presently has a lump-sum of \$100,000 and can earn a 24 percent return (i_c) on this money, the real return (i_m) received is dependent on the annual general inflation rate (f). Suppose f = 10 percent so that from the above relationship i_m = 12.73 percent. This raises the question "Why doesn't $i_m = i_c - f$ = 14 percent?" The difference is the cross-product term, $i_m \cdot (f)$ = 1.27 percent, which represents inflation on the real dollar return that the corporation must have to give it an overall return in actual dollars of 24 percent. In tabular form, the breakout of each component of i_c shows this cross-product term to be an adjustment from real dollar return to actual dollar return:

TABULAR BREAKOUT OF COMPONENTS IN COMBINED RETURN RATE (i_c)

Year	(A) Amount at Beginning of Year	(B) Return Required on Beginning Amount to Cover Inflation (f) (A) · f	(C) Real Return to Investor (i_m) (A) · i_m	(D) Return Required on i_m to Cover Inflation (C) · f	(E) Amount at End of Year (A + B + C + D)
1	100[1]	10.0	12.76	1.27	124.00
2	124	12.4	15.79	1.58	153.76
.	.	.	.	.	.
.	.	.	.	.	.
.	.	.	.	.	.
N	$100(1 + i_c)^{N-1}$	$100 \cdot f(1 + i_c)^{N-1}$	$100 \cdot i_m(1 + i_c)^{N-1}$	$100 \cdot f(i_m)(1 + i_c)^{N-1}$	$100(1 + i_c)^N$

1. All entries are in thousands of dollars

Thus,

$$(1 + i_c)^{N-1} + f(1 + i_c)^{N-1} + i_m(1 + i_c)^{N-1}$$
$$+ f(i_m)(1 + i_c)^{N-1} = (1 + i_c)^N \text{ or;}$$
$$(1 + i_c)^{N-1}\left[(1 + f + i_m + f(i_m)\right] =$$
$$(1 + i_c)^N \text{ when } (1 + i_c) = (1 + i_m)(1 + f).$$

This table shows how the components of i_c can be treated individually to arrive at the fact that $F_j = P(1 + i_c)^j$, or conversely that $P = F_j(1 + i_c)^{-j}$. Here F_j is a future amount in year j and P is a present (year 0) amount. These two factors are used extensively in the present paper.

REFERENCES

(1) Baum. S.. Differential Rates of Inflation," 1978'Fall Industrial Engineering Conference Proceedings, pages 154-159.

(2) Baum, S., "Engineering Economy and the Two" Rates of Return - Mixed Mode Computations," AIIE Transactions, March 1978, pages 81-88.

(3) Commonwealth Edison Company, Engineering Economics, Chicago, 1975.

(4) DeGarmo, E. P., .7. R. Canada, and W. G. Sullivan, Engineering Economy (Sixth Edition), Macmillan Publishing Co., New York, 1979, pages 236-240.

(5) Electric Power Research Institute, Technical Assessment Guide, EPRI PS-866-SR, June 1978.

(6) Executive Office of the President, Office of Management and Budget, Discount Rate to be used in Evaluating Tine Distributed Costs and Benefits, U. S. Government Circular A-94 (Revised), March 1972.

(7) Fleischer, G. A. and A. Reisman, "Investment Decision Under Condition of Inflation," The International Journal of Production Research, Volume 6, No. 2, 1967, pages 87-95.

(8) Jelen, F. C., "Consider Inflation and Comparative Costs Analysis," Chemical Engineering, May 1956, pages 165-169.

(9) Newnan, D. G., Engineering Economic Analysis, Engineering Press, Inc., San Jose, California, 1977.

(10) Power Systems Engineering, Inc., "Comparison of Coal and Nuclear Fuel Alternatives for Process Steam and Byproduct Electrical Power Generation," ORNL/SUB-7257 (Oak Ridge National Laboratory), July 1978.

(11) Smith, G. W., Engineering Economy: Analysis of Capital Expenditures, Iowa State University Press, Ames, Iowa, 1973.

(12) Stuart, D. O., and R. D. Meckna, "Accounting for Inflation and Present Worth Study," Power Engineering, February 1975, pages 45-47.

(13) Sullivan, W. G. and H. A. Fell, "Consideration of Inflation in Comparing Cooling Systems for a Nuclear Power Station," Engineering Economist, Fall 1976, pages 33-49.

(14) Webster's New Collegiate Dictionary, springfield, Massachusetts: G and C Msrriam Co., 1961.

BIOGRAPHICAL SKETCH

William G. Sullivan. Bill is a professor in the Department of Industrial Engineering at The University of Tennessee, Knoxville. He worked several years as a systems engineer at the Medical College of Georgia in August, Georgia, and is a consultant to the Union Carbide Corporation and the Tennessee Valley Authority. He received his Ph.D. degree from Georgia Tech and is a registered professional engineer in Tennessee. Dr. Sullivan is the coauthor of three books and numerous articles.

James A. Bontadelli. Jim has been manager of industrial engineering at TVA since April 1974. He worked twelve years as an industrial engineer and systems analyst and was Manager of Management Systems with Battelle Columbus Laboratories in Columbus, Ohio. Dr. Bontadelli has also been an officer with the U.S. Army Corps of Engineers. He is a registered professional engineer, and his Ph.D. is from The Ohio State University.

INTERFACES
Vol. 10. No. 1, February 1980
Copyright @ 1980, The Institute of Management Sciences
0092-2102/80/1001/0001$01.25

THE USE OF MANAGEMENT SCIENCE TO SUPPORT A MULTIMILLION DOLLAR PRECEDENT- SETTING GOVERNMENT CONTRACT LITIGATION

Steven **Nahmias***

**Department of Industrial Engineering, University of Pittsburgh,
1048 Bencdum Hall, Pittsburgh, Pennsylvania, 15261**

I. INTRODUCTION

This paper describes the analysis of relevant data presented by this writer at a hearing conducted before the Armed Services Board of Contract Appeals involving an appeal of the Ingalls Shipbuilding Division of Litton Industries. The appeal concerned contracts awarded to Litton by the U.S. Navy to build four nuclear submarines and the subsequent impact of changes and delays to these contracts on other shipyard operations. Behind this appeal is the fundamental question of whether or not the government is required to assume liability and reimburse the contractor for additional costs incurred due to “ripple effects” of contract changes on other shipyard opemtions.

II BACKGROUND OF THE CASE

Litton Industries was awarded three contracts to build four nuclear attack submarines (SSN 621, SSN 639, SSN 648/652 on August 24, 1960, November 30, 1961, and March 26, 1963, respectively) at the Ingalls Shipbuilding Division in Pascagoula, Mississippi. In April, 1963 the submarine “Thresher” was lost in a dramatic and tragic accident. As a result of this loss, considerable design changes were made in the plans for the four submarines above. These changes had the effect of requiring considerably more work on these contracts than was originally anticipated. The resultant delays caused the performance of these contracts to be moved into a later time frame. Unfortunately, the later time frame was one in which the company had committed its resources to other contracts for the construction of five surface vessels for the Navy and 14 vessels for three commercial concerns. The Navy ordered the company to give priority to the completion of the submarines.

Litton’s claim was based on the fact that it could not have anticipated the extensive change orders and unreasonable priorities placed on the submarine program at the time the contracts were awarded. On this basis, Litton argued that it should be compensated for additional costs incurred, not only on the submarine programs, but also on the other programs which were impacted by these changes as well.

Due to other contractual obligations, Litton anticipated being at peak manning levels (5500-6000 men) during the period 1965-1969, but actually experienced a

l **Present address: Department of Quantitative Methods, The University of Santa Clara, Santa Clara, California 95053.**

STATISTICS—PATTERN ANALYSIS; JUDICIAL/LEGAL

Reprinted by permission of The Institute of Management Sciences, July, 1980.

manning level inearer to 7000 during this period. As a result, expcricncc(i workers (journeymen) were difficult to acquire. The situation was further aggravated by the fact that the Navy insisted prioriy be given to the submarine program, which resulted in journeymen being shifted from the commercial ship and Navy surface programs to the submarines. Ingalls experienced unusually low efficiencies during this period apparently as a partial result of the high proportion of apprentices ("green labor") working on surface vessels.

As a result of the efficiency loss in both the Navy surface and commercial ship programs, considerable cost overruns in these programs were experienced. Litton claimed a total of approximately $65,000,000 (exclusive of profit and interest) in increilsed costs on seven contmcts to construct five Navy surface and 14 commercial vessels allegedly as a result of the impact of the changes in the three submarine contracts.

III. BECOMING INVOLVED

A formal claim with the Navy for the increased costs experienced on the surface ship programs was filed in 1971. Ingalls received little Navy response to the claim for about 15 months and subsequently treated the Navy's lack of response as a denial of the claim. As a result, a formal appeal was filed by Litton with the Armed Services Board of Contract Appeals.

During the period 1972-1974 a trial preparation group at Ingalls worked closely with attorneys to extract data from Ingalls' records to support the claim. Late in 1974, it became clear that someone was needed to analyze and coordinate the presentation of certain manpower and efficiency data, and the project was suggested to me.

IV. DESCRIPI'ION OF THE DATA BASE

The shipyard maintained a massive volume of data on the progress of each ship during the construction period, This data included production efficiencies, manpower levels, manpower mix, cumulative progress reports, and other items. A problem faced by Litton in developing its claim was to determine how certain relevant data could be presented clearly to emphasize the primary points in the claim. Prior to the time this writer became involved in the case, the company had compiled a computerized sample of the significant data by taking a sampling from the Ingalls direct manpower utilization data base approximately once every two months from 1962 through 1969.

The relevant data used (which was extracted from [2], [3], and [5]) included:

1. Efficiency data for those groups of ships whose schedules were impacted by the changes in the submarine program.
2. Efficiency data for those ships constructed before the majority of the submarine changes were performed.
3. Change orders on the submarine program,
4. Manning levels on the submarine progmm.
5. Change in the skill mix over time.

Efficiencies are computed in the following mannec Based on contract requirements, the total budgeted hours required for each vessel are determined in advance of the actual performance of the work using conventional time standards techniques and historical performance data. The Industrial Engineering Department at Ingalls estimates each month the actual percentage of the totrd project that is complete by direct

observation of the progress of work on the vessel. Cumulative allowed hours per month we obtaiined by multiplying total budgeted hours by the fraction completed and, finally, cumulative efficiency is obtained by forming the ratio of total allowed hours over total hours actually expended. Our studies were based upon monthly efficiencies which were obtained by considering the ratio of the monthly increment of allowed hours over the hours expended in the month. Computations were included for only those vessels that were at least 6% complete because of the unreliability of the estimates of percentage completion in the very early phases of construction. In general, this method of computing efficiency was extremely reliable prior-to 1965: observed efficiencies were generally close to 100%, indicating that the projects in the yard were being carried out within budgets and that the estimates made by the Industrial Engineering Department were accurate.

V. DESCRIPI'ION OF THE STUDIES

The basic issue here was whether or not a causal link between the events on the nuclear subnmarinc program (primarily the Navy's issuance of changes) and the subsequent decline in efficiencies elsewhere in the shipyard could be established. Re-[ained by Litton as an expert in statistics and Operations Research, this writer was faced with achieving two distinct goals which in some sense were contradictory: (1) develop and present the data in a way that the layman could understand the conclusions of the analysis; (2) use statistical methods which were rigorous enough to stand up to critical review by another expert.

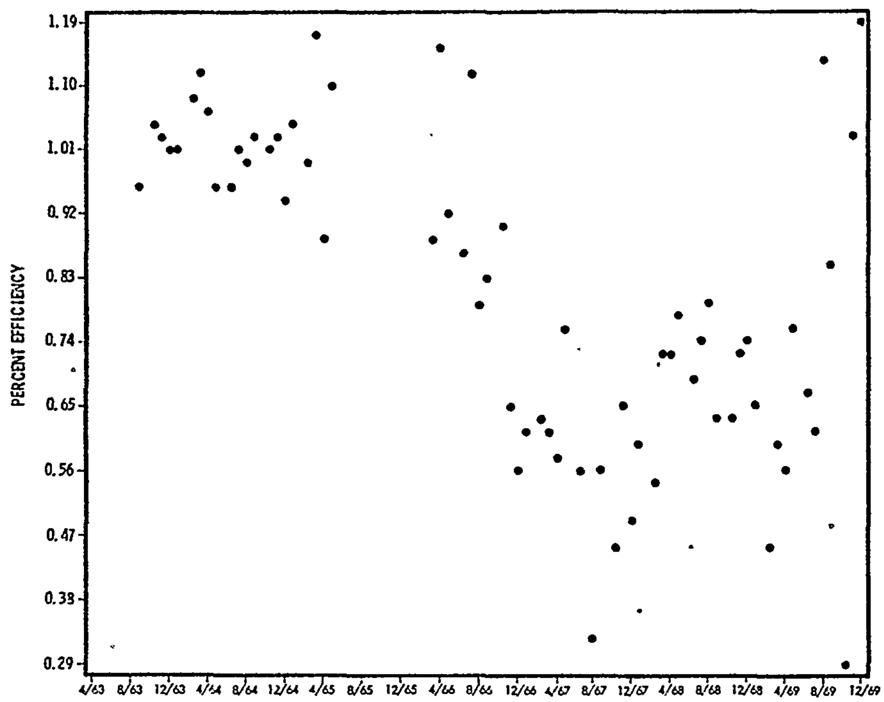
For each of the studies undertaken, a "scattergram" (or picture) of the data was developed so that the conclusions arrived at through the statistical tests could be made graphic and thus, in many cases, self-evident. The scattergrams were used to develop the drawings in Figures 1-4. Each one of the studies performed is described below.

1. Commercial ship efficiency vs time

The first study sought to examine the change experienced in (the efficiency of the commercial ship programs from April, 1963 to December, 1969. In order to obtain the baseline data for this study, efficiency data were used from commercial ship work being carried out in the yard in the pre-impact period (prior to approximately mid-1965), and not included in the claim. The commercial work which was carried out during the impact period (1966- 1969), for American President Lines, Delta Steamship Lines, and Moore-McCormack, was included in the claim. .

Figure I shows the bimonthly efficiencies observed on these ships as a group during the period August, 1963 to December, 1969. Immediately one can see a strong downward trend. Undoubtedly there are many ways one can test for the significance of this decline. By inspection of the figure, two distinct periods were identified during which the monthly fluctuations appeared to be relatively random. As a result we considered the observed efficiencies during the period prior to August, 1965 as one sample and those observed after December, 1966 as.a second independent sample.

FIGURE 1. Commercial Ship Efficiency vs Time.



Letting μ_1 and μ_2' be the true mean efficiencies in the pre- and post-impact periods, respectively, we wish to test the hypothesis that there was no decline in these means. That is, we wish to determine whether or not the data indicate rejecting the null hypothesis, H_0, whére $H_0 : \mu_1 - \mu_2 = 0$, $H_1 : \mu_1 - \mu_2 > 0$. Precisely which test should be used here is determined by the characteristics of the underlying populations. A Kolmogorov-Smirnov goodness-of-fit test was performed which showed that we could not reject the hypothesis that the data for each sample followed a normal distribution. To test for trend, an F test for significance of regression was performed and we found that we could not reject the hypothesis of zero trend in each individual population at either the .05 or .01 levels of significance. Analysis of runs above and below the median was used to test for randomness, which indicated that the data in each sample followed a random pattern. (See [4], for example, for a description of these tests.)

From these tests we may conclude that the observed monthly efficiencies in the pre- and post-impact periods form independent random samples from normal populations. Hence the two-sample t test for difference in means would be appropriate if we were willing to assume that the underlying variation in both periods was the same. A simple inspection of Figure 1 would indicate that this assumption is not warranted. A formal F test for a change in variance indicated a significant increase in the variance from the pre-impact to post-impact periods with an observed F value obtained as the ratio of sample variances of the post- and pre-impact periods of 8.365. Since this value is significant we cannot justify the assumption of equal variances. For this reason the Smith-Satterwaite test [4], which is a slight modification of the two-sample t test but does not require homoscedasticity (equal variances), was used.

Letting $\bar{X}_1$ and $\bar{X}_2$ be the sample means for the observed efficiencies in the pre- and post-impact periods, s_1 and s_2 the respective sample standard deviations, and n_1 and n_2 the respective sample sizes, using the data pictured in Figure 1 gives the following results:

$\bar{X}_1 = 1.026$	$s_1 = .065$	$n_1 = 21$
$\bar{X}_2 = .666$	$s_2 = .188$	$n_2 = 36,$

which gives $Z = 10.47$ and $k = 47$. The observed value of $Z = 10.47$ is *extremely* significant. In fact, had Z been only 2.4 we could have concluded that the change was significant with a likelihood of being wrong of less than .01. The probability that the average efficiency would drop from 102.6% to 66.6% by purely random factors alone is equal to the probability that a t variate with 47 degrees of freedom assumes a value bigger than 10.47. This turns out to be approximately 3.6×10^{-14}, which is an incredibly small number. In other words, the likelihood that an observed drop in the average monthly efficiency from 102.6% to 66.6% could have been due to purely random fluctuations is less than one chance in a trillion!

Note also that the observed average of 102.6% in the pre-impact period implies that projects were being completed on schedule and the estimates of percentages completed made by the Industrial Engineering Department were accurate.

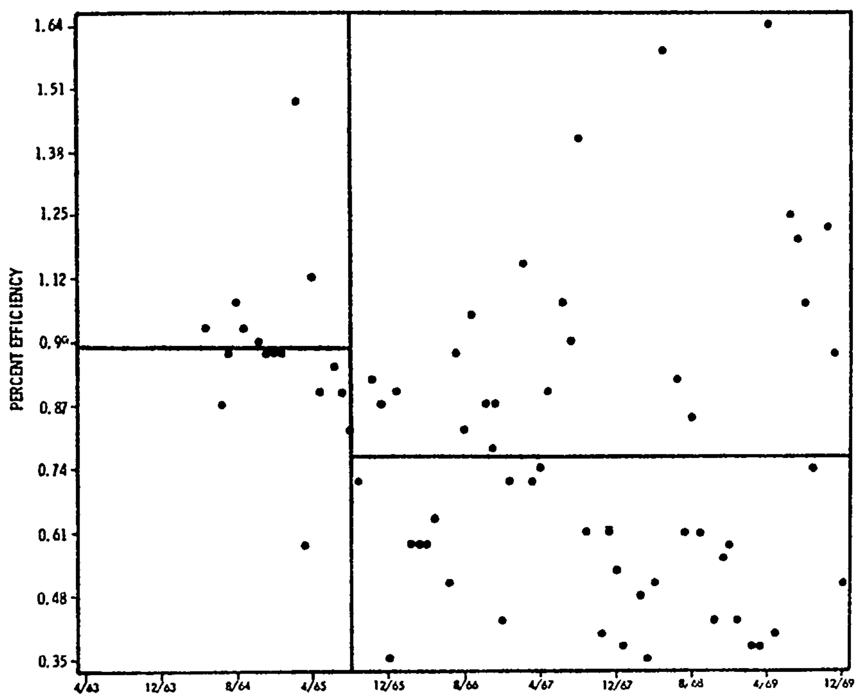
Another conclusion that can be reached from this data is that the underlying variation in monthly efficiencies increased from the pre-impact to the post-impact periods. Not only did the overall average efficiency on the commercial ship program decline significantly, but bimonthly efficiencies exhibited a much greater fluctuation from month to month.

2. Navy surface ship efficiency vs time

During the period of submarine impact within the shipyard, work was being performed on a variety of surface ships for the Navy in addition to the submarine work and the commercial vessel work. In order to study the change in efficiency of [he Navy surface program over time, the work on a hull delivered in Octobcr 1965 was used to develop the baseline data. The Navy surface ships included in the claim were :unphibious assault ships, amphibious transports, and landing ship docks.

For this case, average bimonthly efficiency prior to August 1965 was compared to that experienced after that date. The scattergram displaying the data is given in Figure 2. The vertical line distinguishes the periods under consideration and the horizontal lines are the sample means in each period.

FIGURE 2. Navy Surface Ship Efficiency vs Time.



For this case we obtained:

$\bar{X}_1 = .985$ $\quad s_1 = .180$ $\quad n_1 = 16$

$\bar{X}_2 = .771$ $\quad s_2 = .319$ $\quad n_2 = 52,$

which resulted in $Z = 3.39$ and $k = 45$. The tail value for this test is approximately .0007, which implies the drop is significant for any $\alpha > .0007$. (The tail value may be interpreted as the likelihood that decline in the mean efficiency could be attributed to chance.)

3. Skill mix on commercial ships vs time

One of the contentions of Litton in this claim was that the Navy's insistence that priority be given to completion of the submarine program forced the shipyard to transfer more highly experienced labor (journeymen) from the commercial ship program to the submarine program. This resulted in a buildup of less experienced labor (apprentices) on the commercial ships, which contributed to the resulting efficiency loss.

Two studies were considered to test this contention. First we examined the change in the proportion of apprentices on the commercial ship program over time. The proportion of apprentices working on any day is computed by forming the ratio of the number of apprentices over the number of apprentices plus the number of journeymen working on that day. Only seven major construction crafts were included to obtain this data.

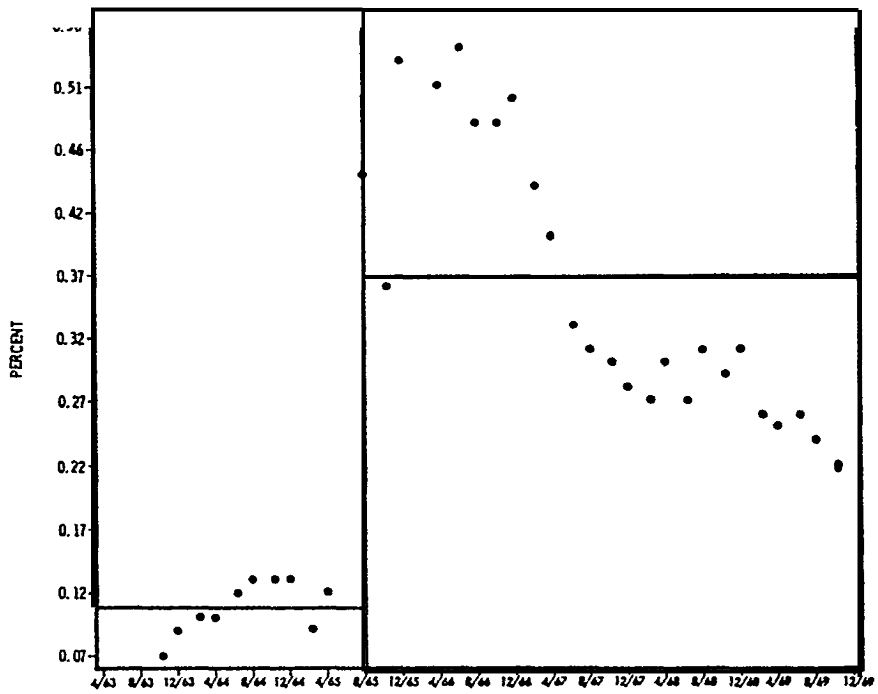
The proportion of apprentices working on the commercial ship program on a bimonthly basis is pictured in Figure 3. We treated the periods prior to and after August, 1965 as generating the two samples and observed the following sample statistics:

$\bar{X}_1 = .110$ $s_1 = .022$ $n_1 = 10$

$\bar{X}_2 = .366$ $s_2 = .122$ $n_2 = 26,$

which, resulted in Z = – 10.27 and k= 29. The tail value for this testis approximately 1.8×10^{-11}, **which is also extremely small (less than one chance in a billion). The** change from 11% apprentices in the pre-impact period to 36.6% apprentices in the post-impact period (horizonral lines in Figure 3) is extremely sharp and points up the radical changes occurring in shipyard operations between these two periods.

FIGURE 3. Percent of Apprentices to Total Commercial Ship Manpower (Seven Major Crafts) vs Time.



4. Proportion of apprentices vs efficiency on commercial ships

The next study shows the correlation between the buildup of the "green" labor (that is, apprentices) on the commercial ship program and the strong decline in efficiency experienced in this program. In order to establish this correlation we treated the following periods: (1) the period when commercial ship efficiency was greuter than or equal to .95, and (2) the period when this efficiency was less than .95. The Smith-Satterwaite test was then performed on the proportion of apprentices observed during each of these periods. The results obtained in this case were:0

$\bar{X}_1 = .147$ $s_1 = .125$ $n_1 = 11$
$\bar{X}_2 = .337$ $s_2 = .099$ $n_2 = 21.$

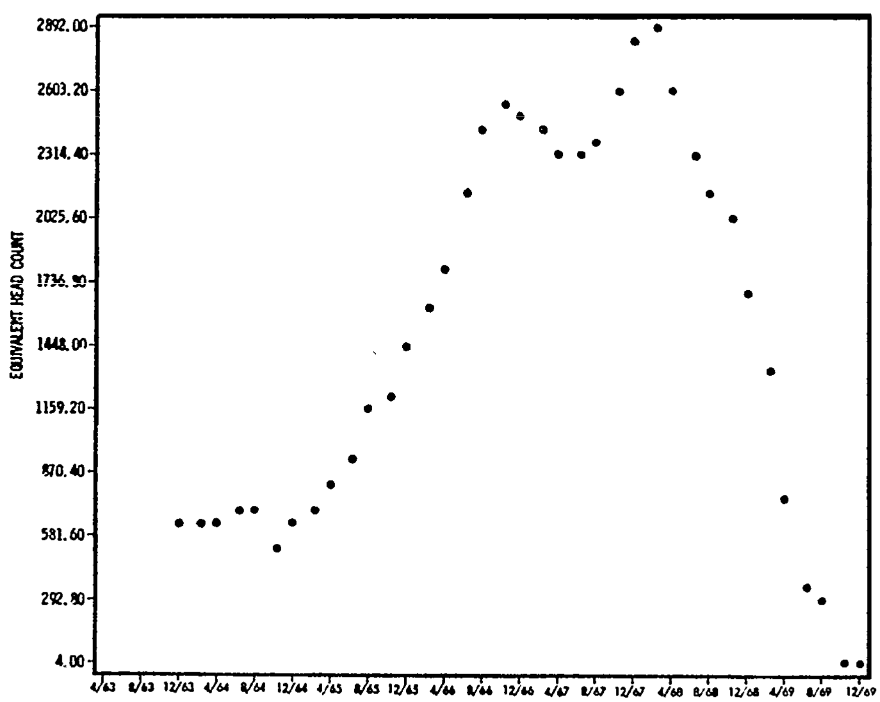
That is, the average percentage of apprentices working on commercial ships when monthly efficiency was 95% or greater was 14.7%, while the average percentage of apprentices working on commercial ships when the observed efficiency was less than 95% was 33.7%. These statistics resulted in $Z = 4.37\%$ and $k = 17$, which gives a tail value of .0002.

It should be pointed out that the existence of a correlation does not in and of itself establish causality. That is, we cannot conclude merely on the basis of this study that the change in the skill mix was the cause of the efficiency decline. However, the analysis provides a means of corroborating other testimony from shipyard personnel indicating that, in fact, this was the case.

5. Submarine manufacturing labor studies

The final series of studies considered the rapid buildup of the number of manufacturing workers on the submarine program and its relationship to the other variables considered. Figure 4 shows the total equivalent headcount of manufacturing labor by month on the four submarines in question: SSN 621, SSN 639, SSN 648, and SSN 652. From this picture, we can see an extremely rapid buildup of manpower on the submarine program starting about June, 1965 and peaking about December, 1967 at the level of approximately 2850 equivalent heads:

FIGURE 4. Total Submarine Manufacturing Labor vs Time.



A peak manning level of about 2000 equivalent heads was originally anticipated for the submarine program. The hypothesis is that hiring beyond anticipated levels would be done at the cost of the other programs and hence would serve to disrupt the general operation of the shipyard.

Three studies were performed which compared the efficiencies for both the commercial ship and Navy surface ship programs, as well as the proportion of apprentices, with the manning levels on the submarine program. Commercial ship efficiency was compared to submarine manufacturing labor by forming the two populations corresponding to the period when submarine manufacturing labor was less than or greater than 2000 equivalent heads. The observed sample statistics in this case were:

$\bar{X}_1 = .888$	$s_1 = .219$	$n_1 = 39$
$\bar{X}_2 = .701$	$s_2 = .191$	$n_2 = 28,$

which gave $Z = 3.72$ and $k = 62$. The tail value for this test was approximately .0002, which implies the decline is significant. That is, the average monthly efficiency on commercial ships during the period when submarine manufacturing labor exceeded 2000 equivalent heads (70.1%) was significantly lower than the average monthly efficiency on commercial ships when submarine labor was less than 2000 equivalent heads (88.8%).

A similar study was performed for the Navy surface ships as well. In that case a cutoff point of 1200 equivalent heads was used. We did not obtain significant results with the 2000 headcount breakpoint. The reason is clear by examining Figures 2 and 4. From Figure 4, the level of submarine manufacturing labor does not exceed 2000 until about June, 1966, while the efficiencies on the Navy surface program begin to decline well before that date. Using the breakpoint of 1200, the sample statistics observed were:

$\bar{X}_1 = .948$	$s_1 = .311$	$n_1 = 26$
$\bar{X}_2 = .743$	$s_2 = .277$	$n_2 = 42,$

which gives $Z = 2.75$ and $k = 48$. The tail value for this test is .004, which is still less than .01 and so can be considered significant. Hence, as with commercial ships, we again see a negative correlation between the efficiencies on the Navy surface program and the manning levels on the submarine program.

The final study attempted to correlate the buildup of labor on the submarine program with the change in the skill mix on the commercial ship program. The reasoning here is that as more journeymen were absorbed into the submarine program, a larger portion of green labor (that is, apprentices) needed to be brought on to man the commercial ship program. Again the breakpoint of 2000 equivalent heads was used for this study with the observed statistics:

$\bar{X}_1 = .244$	$s_1 = .157$	$n_1 = 22$
$\bar{X}_2 = .375$	$s_2 = .100$	$n_2 = 14,$

which results in $Z = -3.06$, $k = 34$, and a left tail value of .002. Hence, when submarine manning was under 2000, the average percentage of apprentices working on the commercial ship program, 24.4%, was significantly lower than the average percentage of 37.5% experienced during the period when submarine manufacturing labor exceeded 2000.

6. Conclusions of the studies

This testimony constituted only a small part of that heard in this appeal. However, it served to provide an objective reinforcement of the opinions and observations

of shipyard personnel who testified from first-hand knowledge about the effect on shipyard operations caused by the changes in the submarine program. Coupled with this other testimony, our analysis supported the claim that the extreme number of changes in the submarine program and its disposition to a later time frame led to changes in the skill mix and losses in efficiency on the other two major programs in the yard and ultimately led to major cost overruns in these programs.

There seemed to be three interconnected "layers" of events:

Stage I.

A. Change orders in the submarine program and shift to a later time frame.

This caused:

B. unanticipated rise in manning levels on the submarine program.

This caused:

C. increase in the percentage of apprentices on the commercial ships.

Stage 11.

A and B both contributed to:

D. decline in efficiency on Navy surface ships,

and

E. decline in efficiency on commercial ships.

(C contributed only to E.)

Stage III.

D and E together created:

F. cost overruns on both commercial and Navy surface ship programs.

VI. DELIVERY OF THE TESTIMONY

Prior to actually attending the hearing, my direct testimony was prepared in writing and was given to the government to review. This direct testimony included essentially the description of the analysis given above.

After I had completed and mailed my written testimony, a young attorney at Pettit and Martin decided to review it for form of presentation and to insure that the relevant points were emphasized. While reading over the revised version, I noticed that the word "significant" had been replaced in certain places by such words as "severe, " "sharp, " "sudden, " and "striking. ' ' The attorney, who is of course not a statistician, was unaware that the word significant has a very precise meaning in statistics, while those other words, which a layman might find more descriptive, did not. Also, he felt that the term "goodness of fit" was a rather obvious example of poor grammar and took it out. These modifications had, of course, no effect on the substance of the analysis nor the conclusions being drawn, and ample opportunity was available to rectify this misunderstanding in the courtroom. The point is that one must be careful to keep track of accepted jargon when crossing over disciplinary lines.

It is worth noting that the government retained one of the nation's largest management consulting companies to provide them with analytical support at a cost reputed to be well in excess of one million dollars. (The total cost of my services to Litton was under one percent of this amount.)

VII. THE OUTCOME

The actual hearing for this case lasted 67 days and resulted in transcripts totalling about 10,000 pages. There were approximately 1725 exhibits presented and the briefs filled 15 volumes of more than 3500 pages.

The testimony described here was presented in April, 1975. Formal hearings on this appeal were concluded in July 1975. The decision on the appeal, which was completed February 22, 1978 [1], awarded $50,439,507 to Litton Industries. Subsequent to the announcement of the formal decision, the government filed a motion for a reconsideration on three counts which was denied, and payment in full wus made by the Navy to Litton in May 1978. This included an additional $380,000, roughly, resulting in a total payment of approximately 51 million dollars.

ACKNOWLEDGEMENTS

The author would like to thank David Anthony and Gregory Smith of Pettit and Martin, Washington, D. C., Robert E. Davis, counsel to Litton Industries, and W. F. Fairley, Jr., of the Industrial Engineering Department at IngalIs, for their assistance throughout the performance of this study. In addition, thanks also go to Mr. George Whetsell for his help with the calculations.

REFERENCES

[l] Armed Services Con!ract Board of Appeals, Decision on Appeal of Litton Systems, Inc., Ingalls Nuclear Shipbuilding Dh'ision, ASBCA No. 17579, February 22, 1978.

[2] Change Order Department Records of Adjudicated Manufacturing Man Hours Change Order, Ingalls Shipbuilding Division of Litton Industries, 1960-1969.

[3] Daily Earnings Reports of Ingatls Shipyard Personnel, 1960-1969 (computer reports based on daily time card data).

[4] Miller. A. and Freund. J. E., Probability and Statistics jor Engineers, Prentice-Hall. Inc., Englewood Cliffs, New Jersey, 1977.

[15] Operating Reports of the Ingalls Shipyard by Ship Hull Number, Department of Industrial Engineering, Ingulls Shipbuilding Division of Litton Industries, 1960-1969.

SPECIAL MAINTENANCE SECTION

Automated preventive maintenance program for service industries and public institutions

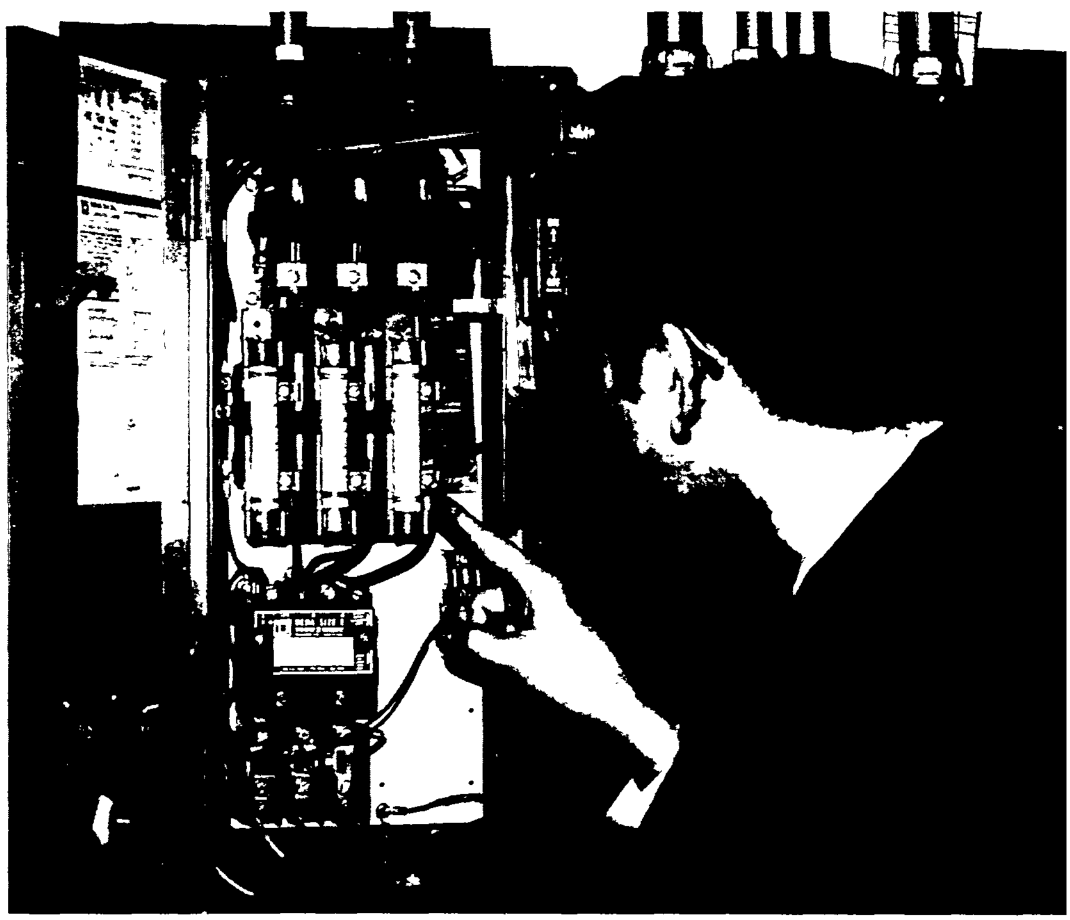
This program for a multi-facility operation can be adapted to other applications.

JACK T. BAKER, Air Force Institute of Technology
Wright-Patterson AFB, OH

The term "preventive maintenance" has been around for years and is used to describe any number of different programs or concepts all designed to prolong the life expectancy of facilities and equipment. The rationale behind these programs is that equipment breakdowns and facility emergencies can be kept to a minimum if the equipment and facilities are kept in a *good* state of repair.

The maintenance of a company's physical plant has always been extremely important, and as work forces become smaller and costs continue to climb, those facilities must be operated and maintained in an efficient and economical manner. Waiting for something to break (which usually creates a panic situation) and then trying to fix it in a hurry is unacceptable.

The roles and concepts of equipment maintenance in the industrial environment have been explored in considerable detail and many pre-



Worker performs routine inspection of electrical switch.

ventive maintenance programs and procedures have been developed. It follows that there is also a need for a viable facility preventive maintenance program in service industries, university complexes, hospitals and government' agencies; however, little has been reported in this area.

Timely maintenance and repair of the facilities operated by these activities have generated a lot of interest as consumers demand more and better services-at a reduced cost. Satisfying those two apparently inconsistent goals is *not* an *easy* task. Likewise, the U.S. Department of Defense. with its tremendous physical plants, is faced with those same challenges and responsibilities as it works to maintain the facilities needed to meet mission requirements. It should be noted that maintaining them is not enough; they must be maintained effciently and effectively.

Facility maintenance program

Within the Air Force, the base civil engineering function is assigned the maintenance and repair of real property assets. This assignment includes:

Operation and maintenance of utility systems including electrical, sewage, heating, air conditioning and aircraft refueling systems.

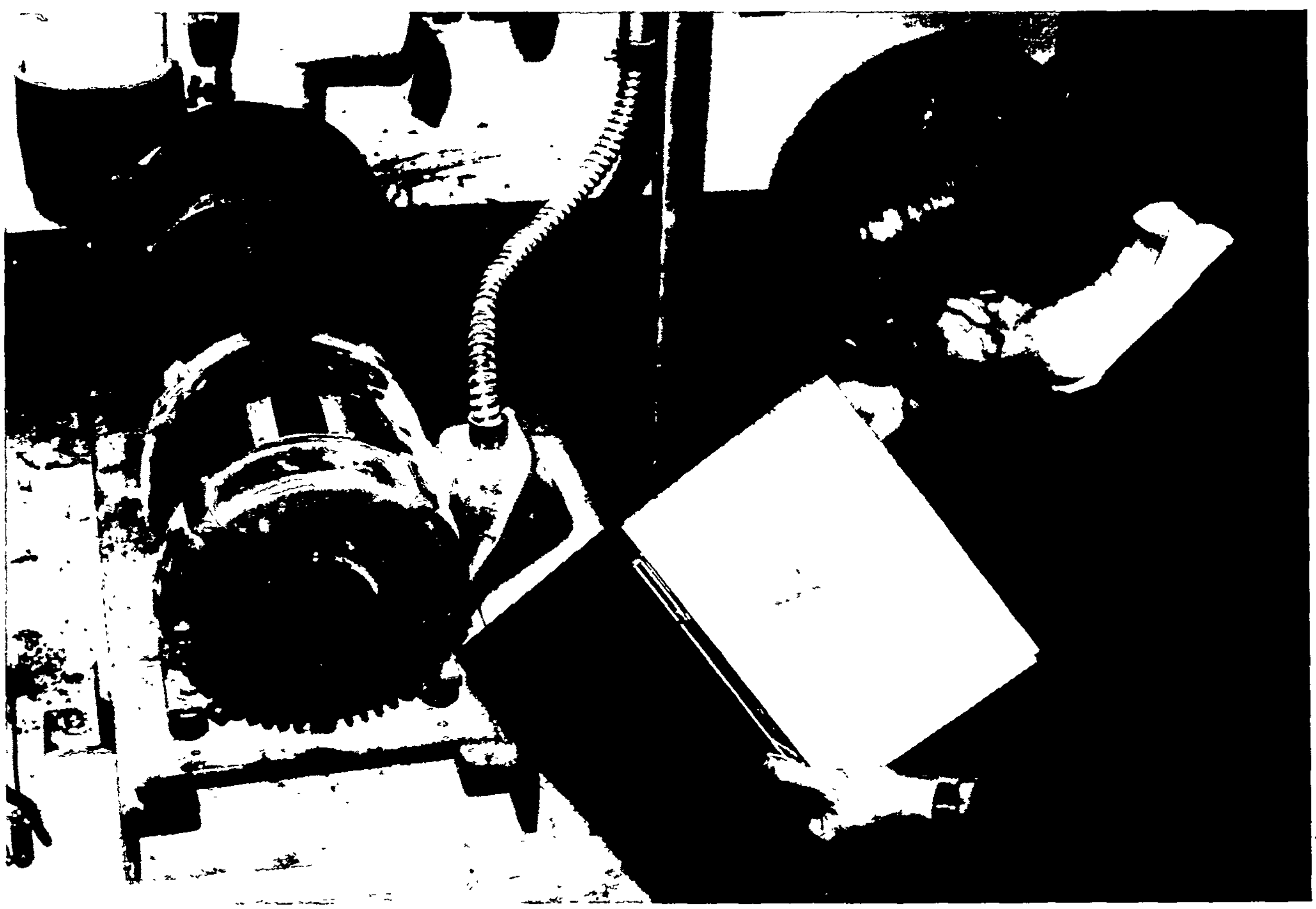
Maintenance and repair of roads and flightlines, including pavements capable of withstanding tremendous stress and wear.

Maintenance and repair of all types of structures, including complex facilities such as hangars, computer operations, laboratories and large warehouses, all of which create unique and complex maintenance problems.

An automated scheduling program is used by the civil engineers to manage the recurring/preventive maintenance aspect of this assignment. Although the program was developed for the Air Force, the general concepts and procedures are applicable to any number of other activities.

The civil engineering activity found that systematic job planning was the best way to meet these requirements and control the costs of the preventive maintenance program. The job complexity, material requirements, diminishing manpower and the complexity of sophisticated utility systems required the development of an automated scheduling program that also provided a means to control man-hour expenditures and provide data for subsequent analysis. The steps taken to establish the civil engineering program (while perhaps varying in magnitude) apply to the development of any program. These procedures establish a system of equipment identification, the determination of maintenance actions required, a schedule of those actions and a record of man-hours and cost data for subsequent analysis.

The first and probably most important step is the identification of equipment to be included in the program. The shop foreman and others then determine the required maintenance actions and the frequency of those actions. Each required action must be performed to the degree which will economically extend or maintain the life expectancy of the item. Considerable emphasis is placed on which task will be performed, realizing that it is more economical in some cases to replace an item that has failed than to continue an expensive labor-intensive maintenance action. The items to be included and the frequency of



Some equipment requires checking with a manufacturer's manual.

MAINTENANCE ACTION SHEET	COST CENTER 461	DESCRIPTION Ice Flaker	MAS NUMBER 017		
REQUIRED MAINTENANCE ACTIONS	REFERENCE	STANDARD HOURS	FREQ	CREW SIZE	HEAVY EQP
1. Check parts for adequate lubrication. Add oil or grease when necessary.	MFG CAT	0.5	W	1	2
2. Clean freezing water system.		2.0	M	1	2
3. Inspect evaporator drum for presence of scale and for proper alignment.					
Clean and adjust as necessary.					
4. Measure clearance between ice cutter or ice removal blade and evaporator					
drum. Adjust as necessary.					
5. Measure clearance of scraper blade and evaporator drum of rotating-drum ice					
flaking machines. Adjust as necessary.					
DATE 10 OCT. 7X	WCF INITIALS STB	DATE 15 OCT. 7X	SUPERINTENDENT'S INITIALS IWG		

Figure 1. Maintenance action sheets list required standard hours for tasks.

performance are determined by:

☐ Local engineer evaluations.
☐ Applicable Air Force manuals.
☐ Manufacturer's catalog, instructions and other literature.
☐ Requirements that must be performed to maintain a warranty.
☐ Actual experience of the maintenance shop.

Required actions must be carefully determined. Overmaintaining an item is a waste of resources, while undermaintaining it is equally wasteful.

Completion of a maintenance action sheet is required to identify task requirements and the following information must be available:

☐ Required actions—Actions to be performed should include a reference column that reflects the manual or other source used to determine what actions are required. It is extremely important to provide a complete yet concise description of tasks to be performed.
☐ Time required—Once the tasks are determined, it is necessary to establish how much time is needed to perform each one. The foreman's and craftsmen's expertise along with man-hour standards (MTM, Navy standards) are used to determine allowed time.
☐ Frequency—How often each action is performed is recorded. Items such as monthly frequencies that would be scheduled to coincide with a weekly requirement are taken into account when completing this step.
☐ Crew size—The foreman determines crew size required to perform the tasks.
☐ Travel time—For each group of required maintenance actions, the need for travel time allowance for heavy equipment is considered.

Only one standard-hour entry per frequency is listed on the maintenance action sheet. This is a summary of the hours for the individual tasks identified for the frequency specified. In the maintenance action sheet of Figure 1, for example, the required standard hours for tasks 3, 4 and 5 are contained in the standard hours column for task 2. Starting with the most frequently required action, the estimated number of man-hours required to perform the tasks for that one frequency is determined. Then, for the next most frequently required action, the estimated number of man-hours needed to perform those tasks plus the time required to perform the more frequent tasks are entered. For example, the standard time listed for the monthly tasks consists of 1.5 hours to perform tasks 2 through 5, and 0.5 hours for the weekly task that would be completed at that time.

The maintenance action sheets are used to set up the initial schedule and are used by the craftsmen as they perform the tasks. The sheets are a ready reference describing the work to be done and provide a means to record pertinent data during the completion of the job.

The last step is the development of the initial schedule. It is extremely important to take such factors as seasonal maintenance requirements

into consideration and to balance the requirements against the available manpower. The schedule should avoid periods of heavy maintenance requirements as well as subsequent periods of little or no maintenance activity.

Automated program

Because of the large number of facilities on an Air Force installation, it was determined that a data automation system was needed to keep up with the workload. The recurring maintenance program was developed as a subsystem of the overall base engineering automated management system (BEAMS) and is designed to aid the base civil engineering organization in scheduling maintenance actions. The program provides a tracking system to identify when maintenance should be performed and summarizes those items scheduled but not completed. In addition, data is provided on the accuracy of man-hour estimates and the cost of maintenance activities in comparison with the cost of equipment. Presently, the program generates cards which are used to schedule maintenance requirements. The man-hours used to complete the tasks are recorded on cards which are keypunched and used to update the computer program. There are, however, plans to put the system on line, thus providing a remote inquiry capability to update, modify and obtain direct access to the program.

The computer file contains information for each item such as a:

❑ Description of the equipment, location and cost of the item and additional data needed to complete identification.

Notice concerning warranty of the item.

❑ Code for the equipment (if it is considered critical).

❑ List of maintenance frequency and standard hours allowed for each frequency.

❑ Record of costs of maintenance performed and man-hours expended.

The file also can be used to record additional management information if required.

The program produces a number of scheduling and management information reports on a weekly and an "as required" basis providing the base civil engineering managers with information that can be used in the design making process. Some of the more common reports are:

Recurring maintenance transaction list-Provides a record of all transactions *and* is used to check the accuracy of the inputs, to update and maintain the files, and to correct erroneous inputs. It is a technician product for program update and maintenance. The list also provides a report showing those items that have been deleted or added to the program since the last run.

Recurring maintenance schedule–Lists those items scheduled for maintenance during the current week and provides information for advanced workload planning for the following week's schedule. This is probably the most important report generated by the system. Basically, it provides a list of those items requiring maintenance based on the date the action was last performed. Part I of the report not only shows those items scheduled during the current week but also identifies those items that had been previously scheduled but not yet completed. Additional information is provided if the item is critical, if there is a warranty in effect or if a completion card was turned in but no hours had been charged to the action.

In addition, several key management information reports are also generated. The first provides a man-hour comparison report which compares the estimated man-hour requirements with the actual man-hours expended on the job. This valuable analysis tool is used to determine if the man-hour estimate needs to be modified or if the craftsmen's productivity needs to be reviewed.

The second report provides information dealing with the cost expended to perform maintenance as compared to the value of the unit. This information can be used to determine the economic worth of performing maintenance and also provides information that can be used to help determine the economic replacement of the item.

Finally, a report is provided that summarizes the hours scheduled for recurring maintenance by shop by month. This report is used to determine future man-hour requirements.

This program is only one of many that has been developed to formalize *a* preventive maintenance program and to insure that those tasks are performed in an efficient and effective manner. Although the program was designed specifically for a large multi-facility responsibility, the concepts and the steps that must be taken are appropriate for any function that needs to establish a preventive maintenance program. The monetary value and tremendous importance of equipment that sustains your operation cannot be overemphasized. Take a hard look at what is being done to insure that the life expectancy of those facilities is met. [IE

Jack T. Baker is a captain and assistant professor of engineering management, Air Force Institute of Technology, Wright-Patterson AFB, OH. He earned bachelor's and master's degrees in industrial engineering from Ohio State University. A senior member of AIIE, he has been dealing with facility maintenance in the Air Force civil engineering career field for several years.

SPECIAL MAINTENANCE SECTION

/

Maintenance goals and management control

A work order system can be established for a maintenance operation, defining goals so that productivity can be measured and/or improved.

JOHN W. RUSZKIEWICZ, A.O. Smith Co., Milwaukee, WI

The maintenance department of a plant need not be neglected when trying to improve productivity. Here is a method involving work orders that should encourage you to try.

Historically, management has been hesitant to introduce labor controls into maintenance departments, due mainly to economic and technical reasons. Economic factors such as the cost of development and continuation of the system are of prime concern. Any system installed must have an adequate return on investment before it becomes a desirable project. What system to use, consultant advice and in-house capabilities also need to be factored into the decision, and these technical considerations ultimately convert into time and therefore economics.

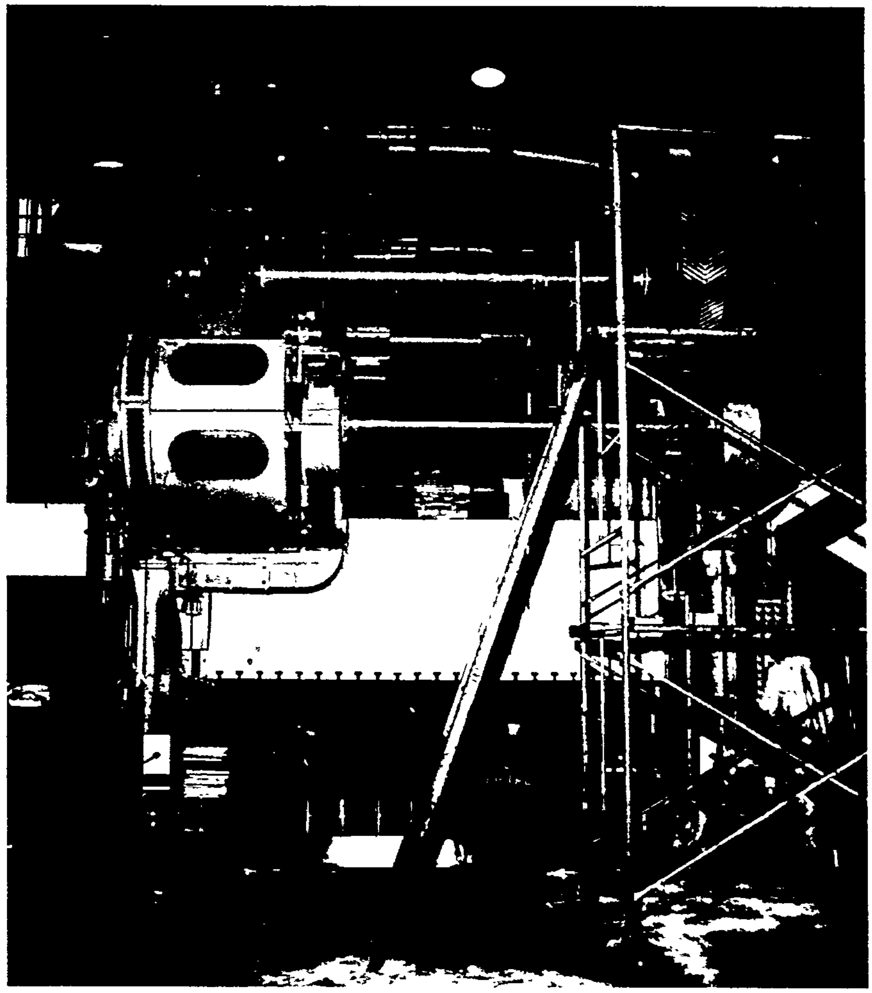
The starting point is the development of a work order svstem which documents all work requests. A sample work order form is shown in Figure 1. A policy of "no work will be started without a work order" needs to be enforced. Meetings are held with production supervision to offer instructions on how to initiate work orders. These meetings serve as a vehicle for feedback on what changes need to be made to increase system acceptance.

A priority system breaks the work down into" manageable segments. Emergency, routine and project work categories cover the range of work. By developing a histogram of the completed work orders for a three-month period, a profile of activity 'can be obtained. as in Figure 2.

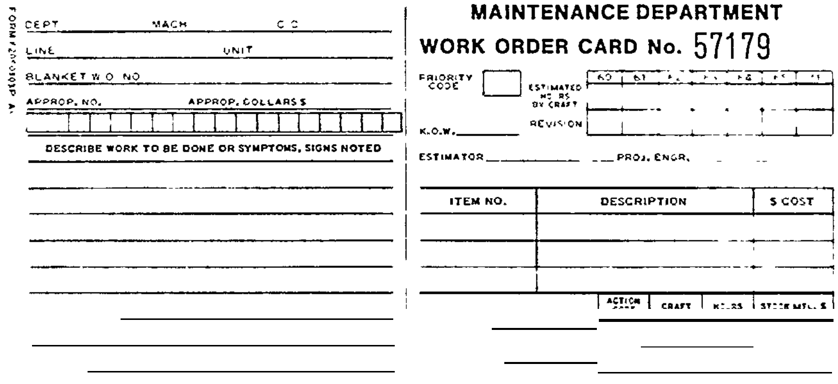
Summarizing "the work orders by work content results in the following:

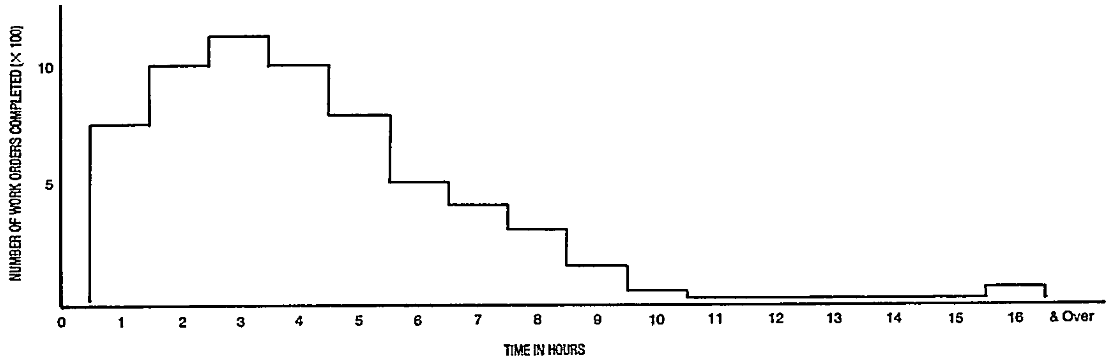
Emergency = 18%
Routine = 42%
Project = 40%

By graphing the average man-hours in the routine and emergency priority for each craft, reasonable trends become evident, as demonstrated by Figure 3. The project work



Major maintenance and refurbishing of a large press consists of completely tearing down and rebuilding the machine.





'igure 2. *Distribution of completed work orders.*

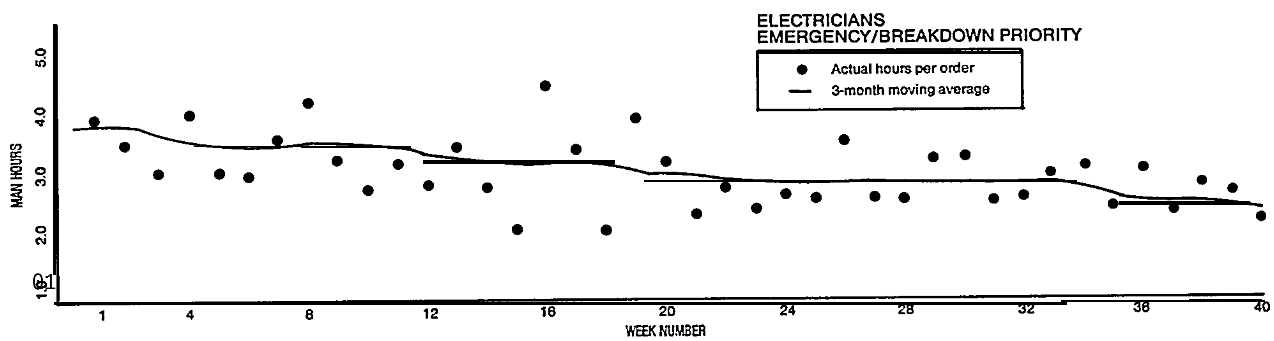


Figure 3. Weekly craft performance chart.

orders, with a cut-off point of 16 estimated man-hours, are judged by performance against estimate, while the routine and emergency work have performance standards set in terms of "average man-hours per work order."

Management now determines goals for each craft for the routine and emergency work. An example of a typical goal for a craft would be to reduce the average man-hours per emergency work order from 3.5 to 3.1. If a management-by-objectives system is in use, these goals serve as a portion of the supervisor's performance appraisal.

The results of the work accomplished are tabulated weekly, then the sorting and summarizing are computerized to minimize the time required to maintain a manual system. The size of the maintenance group should be used as an indicator of how much automation should be used.

Report summaries are provided weekly, and consist of a rolling three-month average as well as last week's results. These reports should serve as a motivator for the first line supervisor to improve his crafts' performance and to also provide recognition.

After a one-year time period, minor system problems will have been resolved and the use of work orders will become routine. You are now in a position to utilize more sophisticated techniques such as multiple regression analysis. This technique will provide you with a mathematical equation indicating manpower requirements of a plant based on production data. An example would be: Maintenance electrician man-hours = .001 X plant machine hours + .004 X previous three-month average number of work orders. Manpower levels should be set by forecasting on a quarterly time period.

In summary, these techniques can remove the problems which traditionally hold back progress in the indirect labor areas. The key to its successful installation is to start out with a system that provides relatively broad goals and to get started today. The system can be refined to your specific needs when the initial phase is completed. Keep in mind that the objective of this management technique is to improve productivity and not have a "direct labor accuracy level."

Using reasonable goals as a motivator can provide you with the tools required to meet and exceed your profit objectives.

John W. Ruszkiewicz is a corporate manufacturing engineering consultant for A. O. Smith Co., Milwaukee, WI. He has performed industrial and manufacturing engineering work for several manufacturing plants in both senior engineering and supervisory capacity. He has BSME/IE and MBA degrees from Marquette University, and is a senior member of AIIE.

SPECIAL MAINTENANCE SECTION

Maintenance by priority

By categorizing various machines and maintenance routines, planned maintenance can be performed on a priority basis as an aid in improving plant productivity.

DILEEP G. DHAVALE, University of Wisconsin-Parkside, Kenosha, WI
GEORGE L. OTTERSON, JR., John Deere Engine Works, Waterloo, IA

/

Reparing a coolant transfer pump on a crankshaft oil hole drill.

preventive maintenance vibration check on a cylinder head transfer line.

Tool maker repairs induction coils.

A well-organized maintenance schedule is a big help in achieving high productivity, but putting together a schedule that is realistic can be very difficult. However, a system that categorizes various equipment and processes and assigns weighted values on the basis of criticality to production goes a long way in achieving a realistic schedule.

Here is a maintenance planning method that provides the manager with consistent, unbiased data on which to base decisions. It is a weighted method that helps quantify some of the many variables that a manager must consider in making maintenance decisions.

As with any complex situation, not all variables that affect the decisions can be quantified, but it is possible to mold this method to fit specific requirements and unique operating conditions by changing factors and their weights. As the method is used and fine-tuned, fewer and fewer changes need be made in the guidelines.

The method is designed so that it uses data that is readily available. It requires very little historical data and hence is useful for plants where such data about machines is nonexistent or expensive to collect.

The concept behind the method is not new. Many firms categorize their manufacturing equipment into several categories (usually not more than five) depending upon the importance of the equipment to the uninterrupted operation of the plant. This method, although useful, is not very sensitive and is not able to take into account many other important factors in determining the criticality of the equipment. Our method takes into account as many as 15 different factors (more could be added or deleted at your discretion). Further, the machines are not lumped into one of the categories, but are ranked according to their importance and criticality.

The 15 factors are divided into two groups: maintenance planning and productivity. The factors relating to maintenance planning are:

- Age of the equipment since last overhaul.
- ❑ Ease of repair.
- Maintenance history of the machine.
- Likelihood of breakdown.
- Danger of machine failure.
- Tolerance.
- Deterioration of the machine and process with no preventive maintenance.
- `Availability of spare parts.

These factors are closely related to the everyday work of the maintenance department, and the maintenance supervisors and managers can identify with them more readily than with the second group which may seem less important from a pure maintenance department view. Nonetheless, the second group of factors incorporates criteria that are important to overall company goals.

The productivity-oriented group of factors includes:

- Transfer line versus free-standing equipment.
- ❑ Number of available alternate machines.
- Normal in-process inventory.
- Investment in the machine (as a measure of downtime cost).
- Average length of repair.
- Average projected machine load.
- The number of operators idled as a direct result of breakdown of the machine under consideration.

All the factors are interrelated and these relationships are so complex that you cannot consider them simultaneously and draw conclusions. For example, take the factor, age of equipment since last overhaul; the older the machine, the more frequently it will need repair. Is the

0019-8234 /80/0200-0024$02.00/0

extra effort worth it? Older machines are less expensive in terms of investment costs, so they generate a higher rate of return on investment, but their probability of unexpected breakdown is higher, which translates into higher idle costs. Generally speaking, older machines will have higher fluctuations in their tolerances (higher process standard deviation) which means changes of producing scrap are higher, and so on. This is just one factor, and we didn't even look at all the possible implications.

Since the relationships are complex between factors and their interactions unknown to a large extent, an alternative is to develop a model that approximates the complex relationships for practical purposes. Our weighted average formula is such a model. It uses data that is easy to obtain and it also uses subjective input to reflect unique operating conditions or requirements and objectives of a firm.

Scoring of factors

Categories in a given factor are scored on a scale of one to ten. The higher the category score for a machine, the greater the amount of maintenance that needs to be performed on the machines in that category to achieve the group objectives.

The objectives for the two groups follow.

Maintenance planning objectives:

❑ Improve efficiency of labor usage.

Reduce unexpected breakdowns.

Reduce downtime caused by breakdowns.

❑ Improve scheduling of predetermined (scheduled) maintenance activities.

Improve efficiency and administration of the preventive maintenance program.

Maintain quality of output.

Maintain equipment performance.

Productivity objectives:

Operate equipment at the highest possible capacity and efficiency, especially the more expensive equipment.

❑ Decrease idle time of equipment, overtime of operators and reduce scrap.

Improve effectiveness of the maintenance department.

The user has the choice to eliminate some of the factors entirely, add new factors, change, add or delete categories in a given factor to change scores. The user should examine critically what follows from his own plant's point of view to make the method suitable for his environment.

The relationship of the two factor groups to the objectives is by no. means direct, nor does there exist a strict dichotomy of factors. A factor in one group may also be important to the objectives of the other group. For example, it is clear that a well-planned maintenance operation and an efficient maintenance department (one of the objectives of maintenance planning factors) contribute to the overall profit maximization goal of the company (one of the objectives of productivity factors). A factor belongs to one of the two groups because it contributes more to the objectives of that group compared to the other group.

To illustrate how categories in factors are scored, the scores for two of the factors are shown in Tables I and II.

Age of equipment

As a machine gets older it needs more maintenance; hence older machines should be maintained more than newer machines. Scores will be higher for categories that need more maintenance to achieve the group objective as shown in Table I. If a machine has had a major overhaul, its age is measured from that time if the overhaul restored the machine to its original capability.

Investment in machine

The expensive machines should be better maintained as they cost more money to own. One way to measure the cost of downtime is to determine the depreciation per year. However, since the depreciation methods and tax life can vary and some machines may have a zero book value (although still productive), it was decided to use replacement cost (not purchase cost) to measure the loss due to downtime as in Table II. In this fashion, the scoring schedules must be determined for all 15 factors.

Weight assignment to factors

The next step is to determine the

Table 1. Scoring equipment age.

Age of equipment	*Score*
Less than 3 years	**1**
3 + to 6 years	**3**
6 + to 10 years	**5**
10+ to 15 years	**7**
More than 15 years	**10**

Table II. Scoring machine investment.

Investment in the machine **(current replacement cost)**	*Score*
Under $50,000	**1**
$50,000 + to $200,000	**4**
$200,000 + to $500,000	**6**
Over $500,000	10

Engine test dynamometer is rebuilt.

Maintenance man works on cylinder liner transfer line.

Table III Weighting of factors in two groups

Ranking	Factor	Weight
Maintenance planning factors:		
1	**Tolerance**	**100**
2	**Likelihood of breakdown**	90
3	**Deterioration of the machine and process with no preventive maintenance**	**85**
4	**Maintenance history of the machine**	**75**
5	**Danger of machine failure**	**65**
6	**Availability of spare parts**	**60**
7	**Ease of repair**	**35**
8	**Age of equipment since last overhaul**	20
Productivity factors:		
Ranking	*Factor*	*Weight*
1	**Average projected machine load**	**100**
2	**Number of available alternate machines**	90
3	**Transfer line/free standing**	**80**
4	**Normal inprocess inventory**	**60**
5	**Average length of repair**	**60**
6	**The number of operators idled as a direct result of breakdown of the machine under consideration**	40
7	**Investment in the machine**	30

Table IV. Maintenance index

No.	*Factor*	*Factor weight*	*Factor score for machine No. 54321*	*Factor weight x factor score*
1	**Age of equipment**	20	**10**	200
2	**Ease of repair**	**35**	**7**	**245**
3	**Maintenance history**	**75**	**6**	**450**
4	**Breakdown likelihood**	**90**	**8**	**720**
5	**Danger of failure**	**65**	**10**	650
6	**Tolerance**	**100**	**7**	700
7	**Deterioration with no PM**	**85**	**3**	**255**
8	**Spare parts availability**	**60**	**10**	**600**
	Total	**530**	—	**3820**

relative importance of factors in each group to achieve the listed objectives of that group. This relative ranking is subjective in the sense that each plant (or company) will get a different ranking based on the business and technical environment to which the plant is subjected. In determining the ranking of factors, the individual user incorporates his special needs, requirements and relative priorities into the model. This molding of the method makes it unique. As more experience is gained or as the environment changes, the model can be fine-tuned by adjusting the weights of the factors. The user can add factors, delete existing ones, and add, change or delete categories of factors. Once the conceptual development is understood, the method can be adapted to any operating condition.

Ranking of the factors in each group and determining their relative importance (as measured by their weights) is crucial to successful application of this method. A suggested procedure is to determine the ranking of factors by arriving at a consensus among the maintenance management personnel. It is helpful to involve higher level managers in this ranking procedure (such as the plant manager) to bring in a plant-wide view in weighting of various objectives. You could use more sophisticated techniques, such as Delphi techniques; in arriving at relative weights for the factors, but those methods may add very little and would be time consuming to implement.

The weights for each group of factors are given as follows: A weight of 100 is assigned to the top-ranked factor in each group. A lower-ranked factor in the group is assigned a weight (out of 100) based on its relative importance when compared with the top-ranked factor. One possible weighting scheme being used is shown in Table III.

Computation of indices

Three different indices are calculated for a machine: maintenance, productivity and machine criticality. The maintenance index is the weighted average of factor scores for maintenance planning and control factors. The higher the value the more critical and important is the machine in

fulfilling the objectives of the first group.

The weighted average of productivity factors gives the productivity index. Again, the higher the index, the more important is the machine from the productivity standpoint.

The above two indices were computed to highlight the major concerns of maintenance department (maintenance planning factors) and plant or corporate management (productivity factors). An overall index (machine criticality), based on both sets of objectives is necessary as it incorporates the concerns of the maintenance department as well as the plant and corporate management.

The machine criticality index is a weighted average of the productivity index and the maintenance index. The weights for the maintenance index and die productivity index now must be determined to combine them to obtain the machine criticality index.

The same group that determined the scores for factor categories can be asked to determine which group objectives are more important to the firm based on:

Corporate objectives, market strategies, pricing strategies.

Existing market conditions and demand mix.

Excess or shortage of plant capability and capacity.

❑ Any factors. unique to the operation of a plant.

Once the group of factors is ranked, the first ranked group gets a weight of 100 and the other groups will be weighted, after comparison, at somewhere less than 100. The machine criticality index of a machine will be the weighted average of maintenance and productivity indices of the machine using the above weights. In this fashion the machine criticality index can be calculated for all the machines in the plant.

A computer program has been developed which calculates and ranks the machines according to the three indices; however, an initial setup effort of collecting the data is required. The data collection work has been simplified by specially designed forms so that a minimal amount of data is required for annual updating and reranking of machines.

A preventive maintenance (PM) program on all machines in the plant is not economical and most times the maintenance departments lack the resources to have a plant-wide program. The ranking of the machines (using any of the three indices as appropriate) will identify the machines where a PM dollar will pay off the best. A set of machines can be determined on which a PM program can be implemented with available resources.

A word of caution: the scores (factor weights) are measured on an ordinal scale. This means that such measurements are good for ranking purposes only. For example, let us say that there are three machines, A, B and C, the machine criticality indices for which are 40, 90 and 50, respectively. All that can be said from this. information is that out of these three machines, B is the more critical, C is critical and A is the least critical to meet the objectives. It is incorrect to say that B is 90 – 50 = 40 units more critical than C, or B is 90 — 40 = 50 units more critical than A.

Index computation

The maintenance index (MI), the productivity index (PI) and the machine criticality index (MCI) will be calculated for hypothetical machine No. 54321. The factor weights listed in the tables will be used. The factor scores (which depend on a given machine) are obtained by evaluating the machine as described earlier. Then, referring to Table IV, the maintenance index for machine No. 54321 is 3820/530 = 7.208 out of a maximum possible 10.

Sometimes it is preferred to express the indices out of a maximum possible 100. For machine No. 54321 with that base, the MI would be 72.08. The productivity index is obtained in similar fashion. Let us assume that the PI for machine No. 54321 is 61.93.

To compute the MCI, the group weights must be determined. Assume the weights for the group were determined as:

Maintenance planning factors: 65

Productivity factors: 100

MCI for machine No. 54321 is:

$$MIC = \frac{72.08 \text{ X } 65 + 61.93 \text{ X } 100}{65 + 100}$$

= 65.93

The algebraic formulation of the method follows:

Let

X_{1jk} = the factor score, machine No. k, for ith group (i = 1, 2) and jth factor (j = 1, 2, 3----)

W = factor weight of jth factor in ith group

v_i = group weights

Then:

$$MI_k = \frac{\Sigma_{j=1}^{8} (w_{1j} X_{1jk})}{\Sigma_{j=1}^{8} (w_{1j})}$$

$$PI_k = \frac{\Sigma_{j=1}^{7} (w_{2j} X_{2jk})}{\Sigma_{j=1}^{7} (w_{2j})}$$

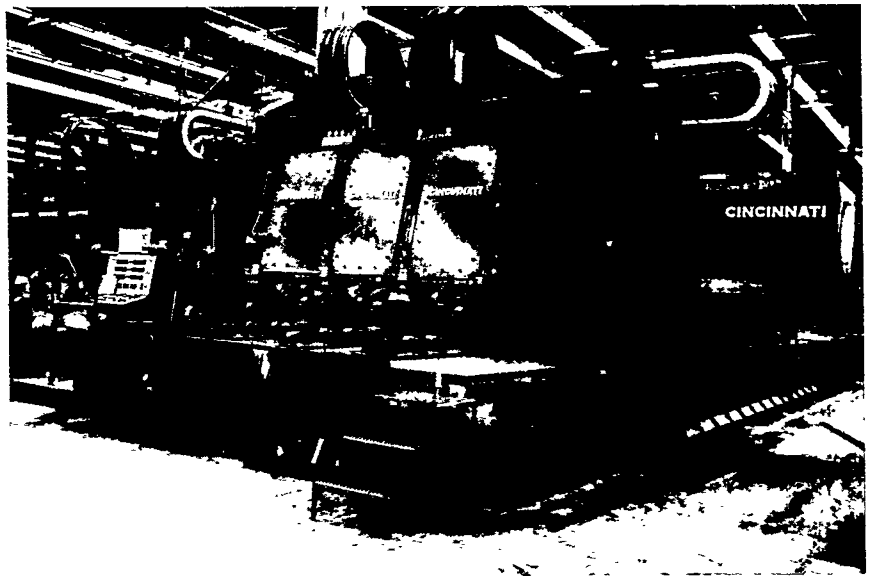
$$MCI_k = \frac{v_1 MI_k + v_2 PI_k}{v_1 + v_2}$$

IE

Dileep G. Dhavale is an associate professor of production/operations management at the University of Wisconsin-Parkside. He has a BS in mechanical engineering from IIT, Bombay, an MS in industrial engineering from the State University of New York at Buffalo, and a PhD in business administration from Pennsylvania State University. His current research interests are in the areas of accounting and production management.

George L. Otterson, Jr. is Works Manager, for John Deere Engine Works, Waterloo, IA, where he is responsible for overall manufacturing operations. He has had many years of experience in various industrial and manufacturing engineering areas. Otterson holds BSME and MBA degrees from the University of Nebraska.

Keep million-dollar machines cost effective



The machine tool area can be made more cost effective, as demonstrated by the computerized simulation model, by replacing a 2 112-ton capacity *crane used for loading/unloading with one of twice that capacity. Then reassign four workers to more productive work. This 3-spindle, 5-axis gantry unit is machining titanium.*

Equipment engineers at McDonnell Aircraft Co., St. Louis, MO, are constantly faced with purchasing and/or replacing equipment in fabrication areas due to fluctuations in production rates, equipment utilization schedules, raw materials, etc. Problems are amplified in the 3-spindle, 5-axis gantry machine tool center because of the varied situations in which a job may run and the number of resources required. At a cost of more than $ l-million each, these machines represent the company's most significant capital investment in computer aided technology. The positioned part loads vary from $1O,OOO to $60,000 per load before roughing or finishing cuts.

To make these areas as cost-effective as possible, a simulation method is used which attempts to provide the necessary facts so that reasonably sound decisions can be made. While the method has been used successfully in many fields of engineering and science, the advent of the computer has increased its utilization as a managerial decision making tool'. Coupled with a special language such as the general purpose simulation system (GPSS)-', a model study of equipment acquisitions and resource allocations is feasible.

HULAS H. KING
McDonnell Aircraft Co.
Division of McDonnell Douglas
St. Louis, MO

HALUK BEKIROGLU
Southern Illinois University
Edwardsville, IL

Nature and scale of problem

Work orders for major fittings of several aircraft models are received at the 3-spindle, 5-axis gantry area with varying priorities, run-times, and special running conditions. Each 5-axis gantry has three available loading positions, allowing the head of the machine to move from load to load without stopping for adding new parts. There are four absolute gantries scheduled for aluminum jobs only, and 12 incremental gantries designed to run titanium jobs for close tolerance requirements. Because of the size and weight of the parts, overhead cranes are used to load and unload these jobs. Crane No. 1 (10,000 lb capacity) must be used for titanium jobs, but crane No. 1 or No. 2 (5000 lb capacity) can be used for aluminum jobs. The bulk area, where most of the jobs are received, holds up to 100 jobs. Six set-up men prepare, load and unload the parts, and clean off the machine beds for new jobs. Two fork trucks move parts in and out of the area. The various types of aircraft parts fabricated on the 5-axis gantry machine tools are separated into three groups, each with an estimated time of flow through the area.

Group A aircraft–These work orders arrive on an average of 15 per day within three part load time increments of 96 ± 30 minutes. Due to current assembly jig dates, these jobs have priority over other aircraft models. Approximately 40% of these orders are aluminum and the remainder are titanium. When received, all group A jobs are sent to the bulk area where set-up men and expediters prepare required cutters, tools, and part programs to run the parts. This takes 120 ± 60 minutes for aluminum jobs, but titanium jobs are already set up when received. It takes approximately 60 minutes to clean up, 45 ± 15 minutes to load, 30 ± 15 minutes to unload and 120 ± 30 minutes to run an aluminum job. A titanium job takes 20 ± 10 minutes to clean up, 60 ± 15 minutes to load, 60 minutes to unload and 240 ± 30 minutes to run.

Group B aircraft–Work orders of this group arrive on an average of 30 per day within three part load time increments of 48 ± 16 minutes, requiring 30 ± 10 minutes to prepare them for running. The aft section of these parts is sent by fork truck to a 3-spindle 3 in. profiler for slot cuts. The fork truck brings one load at a time, taking 30 ± 15 minutes. Because of logistics, this machine uses crane No. 1 only, taking 120 ± 40

minutes to load, and, 360 ± 60 minutes to run each load. No crane is required to unload. The truck driver unloads the parts and brings them back to the 3-spindle, 5-axis area where they are merged with the forward section, fabricated on the 3-spindle, 5-axis machine tools. All group B parts are aluminum. The forward section run-time is about 180 ± 60 minutes, with loading taking 120 ± 30 minutes, and unloading taking 60 ± 30 minutes.

Group C aircraft–Work orders are received for this group every 60 ± 30 minutes. These jobs are all titanium and must be run on incremental machine tools. It takes 90 ± 45 minutes to load, 30 ± 15 minutes to clean the machine bed before loading, 45 ± 15 minutes to unload, and 360 ± 60 minutes to run.

Each crane is used by maintenance personnel approximately 2 hours per day lasting about 20 minutes exponentially distributed. Servicing usually occurs during off hours or at low peaks to prevent interference with production runs.

Model development

Implementing a new production line, considering a major facilities change, and isolating cost problems in the manufacturing process, require analytical efforts that support some of the most critical decisions made by production management. Yet in the mass of data gathered, sorted, charted, and summarized prior to starting the decision process, the net effect of all specified variables is often obscure.

To avoid similar problems, a GPSS model of the 3-spindle, 5-axis machining center was developed that allows production management to ask *what if* questions about many relationships of time, materials, equipment, and human resources.

Recognizing the flux of dynamic interactions in the machine shop, this model was constructed in modular units depicting the flow of production parts by aircraft type. Once tested individually for validity and adaptation to real-world conditions, these modules were combined to test the overall impact and relationship of the resources employed throughout the model.

After designing the system to be analyzed, a flow chart of the operational system was prepared defining its functions. Historical DNC management data reports and methods engineering standard procedure data were used to produce reliable flow times for the functions defined in the flow chart. Using the flow chart and event cycle data, a GPSS program was written and run on an IBM 370/168 central processing unit (CPU) via a remote Data 100 input/output terminal.

Output sheets from the initial computer simulation were checked against known system actuals via comparison with several advanced methods studies. Upon recommendations from functional personnel in the 5-axis gantry area, a few minor adjustments were made to the model to better represent the real-world.

Preliminary results

The 3-spindle, 5-axis gantry model was run for one day to reach a steady state. Initial runs for 15 and 30 days showed about 56% utilization of crane No. 1 for maintenance, loading, and unloading. Normal crane utilization policy according to methods engineering is about 80%. The work load forecast in this area is anticipated to increase by 95% when the production rate for group A aircraft is increased to 15 per month. Projected sale of a new fighter model to the Marines will add to the work load in this area also.

According to Plant Engineering, the cost for upgrading crane No. 2 to 10,000 lb. capacity is about $15,500 parts plus labor. This cost is very small in comparison to costs that may be encountered by not servicing the gantry area effectively.

In addition to crane utilization, this model also shows the utilization of other resources in the area and the queues that formed for service.

Observations made by this simulation include:

• With the high utilization for the 3-spindle 30-in. profiler on the split group B orders (99%), additional new equipment or subcontract work from this area is needed if slot cuts are required for new aircraft models. On the other hand, group B production is on a downswing and subcontract work may have to be recalled to maintain the current high utilization.

• More incremental 5-axis work should be added to current loads as is evident by the low utilization percentage of 5.3%. Work designed to run on absolute machine tools could be run on the incremental machines.

• The bulk area could be shared with the 4-spindle 40-in. machine tool since only half of its space is loaded.

• The setup men are doing a good job of keeping the machine bed loaded, but they are working only about 20% of the time. Four of these men could be located in another area or trained for other jobs. This saving alone (4 setup men X $14,000/year = $56,000) is enough to justify upgrading crane No. 2.

Several basic conclusions may be drawn from this simulation model to assist in making decisions about fabrication operations and equipment acquisitions for the 5-axis gantry area. Besides the current utilization level of equipment and manpower resources, the queue statistics and flow diagram enable functional personnel to evaluate the relationship of dependent events over a specified time frame with a built in randomness feature that approximates real-world occurrences. GPSS output statistics are helpful in preparing targets and workload forecast for similar production jobs. The crane utilization statistics serve as a determinant for installing additional cranes or modifying the current ones to support more varied load combinations. Even though this simulation is geared toward crane utilization, it also provides a basis for making changes in the load mix on the machine tools and also the quality and type of resources servicing this area.

The use of a model for analyzing alternative operational policies is an extremely useful method for producing inputs to the management-decision process. Although several types of models are available, a procedural simulation model can be developed in situations where it is virtually impossible to formulate other types due to the complexity of the system to be studied.

References

' Project 75.20 "Influence of CAM on Productivity;" Report to the AIA Manufacturing Committee, September 1976.

"General Purpose Simulation System V OS/DOS User's Manual No. SH20-0851;" IBM Corp., White Plains, New York, 1973.

Digital Electronics for Microprocessor Applications in Control of Manufacturing Processes

WILLIAM M. MARCY
Department of Industrial Engineering
Texas Tech University
Lubbock, Texas 79409

Abstract: The rapid development of microprocessor devices invites the industrial engineer to consider using microprocessors to solve data acquisition, machine control, and process control problems in ways that previously would have been apriori uneconomic. The initial simplicity of the microprocessor is often lost when the engineer finds that microprocessors are usually embedded in conventional digital electronic circuits. Fortunately, only a small class of digital electronic devices serves a variety of functions. When their operation and application is understood on a functional basis, the original simplicity of the microprocessor is Iargely retained. The suppliers of microprocessor products provide not only the microprocessor itself but also a wide range of supporting "chips" which allow the user to realize a microcomputer system of considerable power and flexibility. Nevertheless, the user usually finds a need to understand and use more conventional digital electronic circuits in conjunction with the microprocessor and its supporting devices.

- The trend in design of computer hardware has been to integrate increasingly complex electronic devices into ever decreasing numbers of semiconductor components or "chips." The minicomputer resulted from the first generation of integration when it became possible to construct a functional computer from small and medium scale integrated circuit devices on one or at most a few printed circuit boards. Although miniature in size, the minicomputer offers substantial computing power at low cost.

The present state of the art of large scale integration makes it possible *to* integrate the electronic functions of a computer into one or at most a few integrated circuits. The central processor, when implemented as a single semiconductor chip is called a microprocessor. When the microprocessor is combined with associated memory and support devices one realizes a microcomputer. Like the minicomputer, the microcomputer offers substantial computing power at even lower cost. Minicomputers have grown in power and capability and challenge main frame computers in some applications. Similarly, microcomputers are growing in power and complexity and now challenge both main frame computers and minicomputers in applications involving stand-alone or real-time computing requirements.

Received November 1979. Paper was handled by Manufacturing and Materials Department.

The trend by microprocessor device manufacturers is to integrate common supporting circuitry into support chips or even into the microprocessor chip itself. As this trend progresses, the need to understand and use conventional digital electronic circuits in conjunction with microprocessors diminishes. This not only results in a simpler understanding of functions it also reduces number of parts needed for a given application. Additional benefits of increased reliability are achieved due to the stringent quality control methods used to fabricate large scale integrated circuits.

There remain several areas concerning microprocessor applications that are well served by conventional digital electronic circuits. These areas include address decoding, data and address bus buffering, data latching, data multiplexing, and analog-digital conversion.

The objective of this paper is to present a functional understanding of these areas. No attempt is made to present a theoretical basis for device operation, and indeed, it is not usually relevant to the industrial engineer's consideration of microprocessor applications.

Microprocessor Systems

The major features of a microprocessor system are illustrated in Fig. 1.

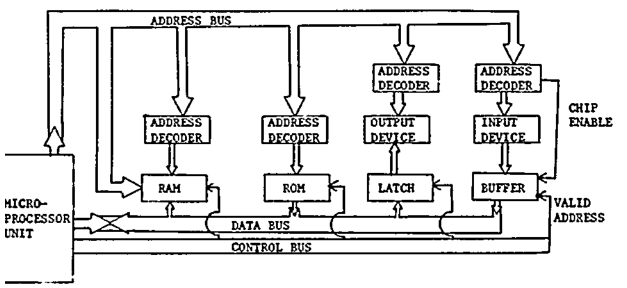


Fig. 1. Major features of a microprocessor system.

The microprocessor unit (MPU) communicates with external devices and circuits by means of an address bus, a data bus, and a control bus. The term "bus" is used to describe a communication path interconnecting the microprocessor unit with other devices. A bus is often composed of parallel paths or wires each of which is capable of transmitting one "bit" of information. The address bus consists of a set of signals representing, in binary form, the "address" of an external device (or memory location) that is to be activated. An address bus consisting of sixteen wires, each of which represents a logic 1 or a logic O selects one of $65,536_{10}$ distinct memory addresses. A data bus consisting of eight wires can transfer 8 binary digits (bits) simultaneously to or from other devices. An address bus is usually a one-way street, leading away from the MPU. A data bus on the other hand is usually a two-way street leading data into the MPU and away from the MPU (frequently called a bi-directional data bus). An important application of conventional electronics is in buffering some of the devices connected to a bus in such a way that they respond only when "spoken" to and also providing means for disconnecting them so that they do not interfere with other devices connected to the same bus.

Address decoding circuits continually monitor the address bus, and generate a chip enable (CE) signal only when a specific address or range of addresses is present. Latches and buffers serve to hold data until called for by the MPU or until an external device can respond to it.

The control bus provides a variety of signals that serve to not only synchronize the operation of the MPU and associated devices but also to provide a means for interrupting the MPU when priority service is needed. Representative signals found on the control bus would include the system clock, the valid address, and the interrupt request signals. The system clock is a reference signal generated either inside the microprocessor chip or by an associated chip to time the execution of instructions and data transfers. The valid address signal is used to inhibit the response of devices connected to the address bus during transient logic states. The interrupt request signal is used to interrupt the processing of instructions in an orderly manner to direct the MPU to a higher priority subroutine that services the interrupting device or system. These signals, in conjunction with the address decoding logic, serve to synchronize the MPU with external devices and circuits.

Combinatorial versus Sequential Digital Circuits

The operation of a microprocessor system is inherently synchronous, i.e., the MPU is controlled by a system clock (or master timing generator) that determines the timing of all events and most significantly the elements of the operation cycle (fetch-decode-execute cycle) of the MPU.

All digital electronic circuits (including the microprocessor) are composed of one or more switches (gates) that receive high or low voltages as inputs representing logic 1's and logic O's and whose outputs are also high or low voltages representing logic 1's and logic 0's.

Combinatoriral logic circuits (also called asynchronous or direct logic) respond immediately as the inputs change. Sequential logic circuits (also called synchronous logic) respond to inputs only at certain specific times as controlled by the application of a master clock pulse.'

Digital electronic devices that implement the logical AND, OR, NAND, NOR, inversion, and buffering functions are combinatorial devices. Digital devices realizing bistable (two stable states), latch, counter and memory functions are usually sequential devices requiring a clock input to time their responses to input signals. Both sequential and combinatorial logic devices have uses in microprocessor applications.

Combinatorial Digital Logic

Logic circuits are composed of high speed electronic circuits called gates. Most digital gates can switch state in less than one microsecond and usually in nanoseconds. Input voltages representing logic 1's and logic O's can in principle be any pair of distinct voltage levels. In practice, these are standardized for a given logic family such as transistor-transistor-logic (TTL). The TTL logic family uses +2.0 to +5 volts for logic 1 and O to 0.8 volts for logic O. (Voltages between the low and high ranges result in an indeterminate state.)

The Buffer

Each gate output acts as a power source providing signals to the inputs of other gates. The amount of power available from a gate output is limited. If too many other gate inputs are connected to one gate output as a signal source, the signal source becomes too heavily loaded and either stops functioning or else becomes unreliable. To expand the drive capability of a gate output we often connect the gate output through either an inverting or a non-inverting buffer to other gate inputs. Symbols for an inverting buffer, non-inverting buffer, and a three-state buffer are shown in Fig. 2. (NOTE: POWER AND GROUND CONNECTIONS TO INDIVIDUAL ELEMENTS ARE NOT SHOWN.)

The non-inverting buffer (or simply buffer) is an amplifier that can provide higher current levels so as to expand the number of gate inputs that can be driven by a given logic source. The inverting buffer does the same job, but also changes a logic 1 to logic O and vice versa.

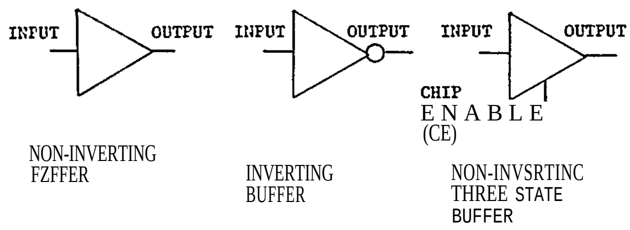


Fig. 2. Logic buffers.

Three state logic buffers may be obtained with or without inversion. These logic devices have a unique third state in addition to logic 1 and logic O. When the chip enable (CE) signal is present, the three-state buffer acts like a conventional buffer. When disabled by applying logic O to CE, the output assumes a high impedance state and is effectively disconnected from the other circuits. Three state buffers make it possible to set up two-way communication on a bus and thus place the direction of data movement under program control. Fig. 3 shows the packaging of two common buffers, a TTL 7404 Hex Inverter, and a TTL 741 26C three state non-inverting quad buffer. Note that the 7404 provides six independent inverters whale the 74126C provides four independent three state buffers. Each package has 14 electrical connections (pins) and a reference notch for pin identification. Two pins connect power to the devices; one is labeled with the convention Vcc and the other Grid. (NOTE: INTERNAL POWER AND GROUND CONNECTIONS ARE NOT SHOWN'.)

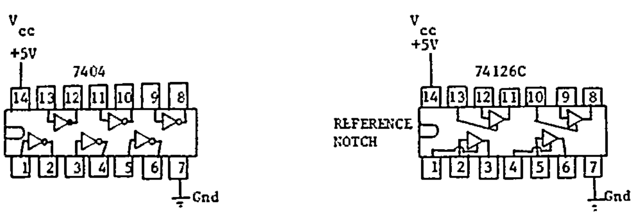
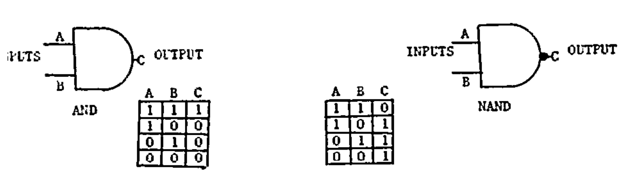


Fig. 3. Integrated circuit buffer devices.

The AND and NAND Gate

The **AND** gate produces a logic 1 (high) output if and only if all inputs are simultaneously logic 1 (high). The NAND (not AND) is simply the AND followed by an inverter. The utility of the NAND comes from the fact that any digital combinatorial circuitry can be synthesized using only NAND devices and inverters. Fig. 4 illustrates the AND and NAND symbols and their corresponding truth tables.



A	B	C
1	1	1
1	0	0
0	1	0
0	0	0

A	B	C
1	1	0
1	0	1
0	1	1
0	0	1

Fig. 4. AND-NAND logic.

The OR and NOR Gate

The OR gate produces a logic 1 output if any of the inputs are logic 1. The NOR gate is the OR gate followed by a logic inverter (nor OR). The utility of the NOR is like that of the NAND in that any combinatorial digital logic circuit can be synthesized using only NOR logic and inverters. Fig. 5 illustrates OR and NOR symbols and their truth tables.

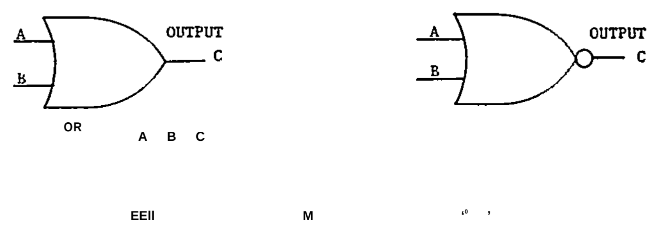
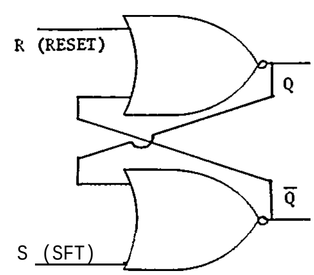


Fig. 5. OR-NOR logic.

Sequential Logic

Sequential logic elements are those which change state only when the proper set of input signals and timing signals are applied. Sequential logic elements that exhibit two stable states are comionly called bistable or flip-flop circuits. The bistable circuit is basically two logic gates with the output of the first connected to the input of the second and vice versa as shown in Fig. 6.



R	S	Q
0	0	INDETERMINATE
0	1	1
1	0	0
1	1	FORBIDDEN

Fig. 6. R-S bistable circuit using NOR gates.

The bistable circuit will retain its logic state so long as power is uninterrupted and no switching signals are applied. The basic deficiency of this circuit involves R and S receiving the same logic value prior to Q (or Q) reaching a stable logic 1 value. If we apply R and S signals of the same logic value simultaneously, the final state of the bistable is unpredictable. Sequentially applying R = O and then S = 1 sets Q = 1 and Q = 0. Similarly, applying S = O then R = 1 results in resetting Q = O and Q = 1. The states are otherwise unpredictable.

A more complex bistable circuit called the. J-K bistable employs master-slave R-S bistables and associated AND gates to overcome the limitations of the R-S bistable. Figure 7 illustrates a master-slave J-K bistable circuit and its associated truth table.

The inputs J and K control the output Q only when me clock switches from high to low. The clock then synchronizes data transfer into the bistable device. The use of two bistable devices provides effective buffering between input and output. When several bistable circuits are integrated into a single package, we have a most useful device called a latch. The latch provides a means for holding data and effectively provides an interface between the synchronous behavior of the MPU and the asynchronous need of some external device such as numerical display or control signals for power relays.

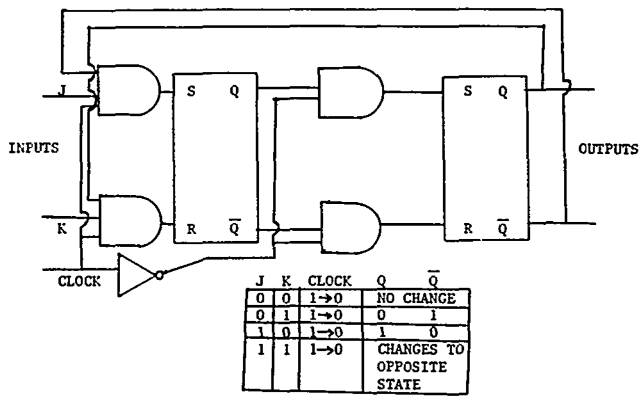


Fig. 7. Master4ave bkteble (flip-flop) circuit.

Figure 8 illustrates a TTL 7475 quad latch in the form of a 16 pin digital integrated circuit.

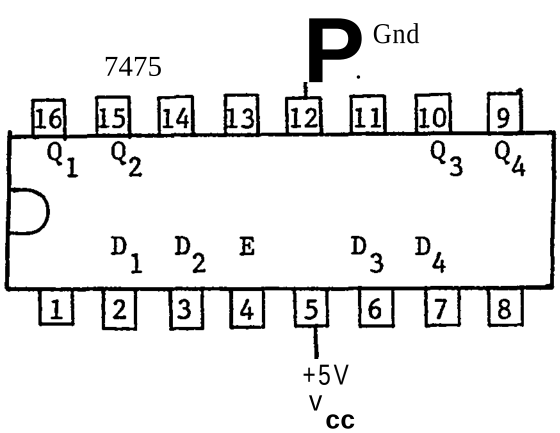


Fig. 8. Quad-latch type 7475 integrated circuit device.

The outputs are labeled Q_1, Q_2, Q_3 $Q_4$and the corresponding inputs are labeled D_1,D_2,D_3, and DA. Pin 4 labeled E is for data enable, i.e., the clock input. So long as pin 4 is in the logic 1 state, data at Q_1 ~ to Q_4 follows data at D_1 to D_d. When E makes a transition to the logic O state, the data present at that instant is “latched” and retained at Q_1 to Q_4. No further change in output occurs until E again assumes the logic 1 state.

In keeping with the trend toward increased integration, an addressable latch is available that allows 8 bits of data to be retained. Figure 9 shows a 74LS259 8-bit addressable latch in a 16 pin package.

This device contains eight bistable circuits and the logic to decode a 3 bit address. The output data appears in parallel on pins Q_0 to Q,. The data to be latched is presented one bit at a time at the data input pin. The clock signal present at the enable pin (E) clocks the value present at the data input into Q_O to Q_7, depending on the address present at the address pins A_O to Ao. If the address 101_2 is present, the value will be latched into Qs;if 1112, then Q,; if 000_2, then Q., etc. An additional input is available to clear all outputs to logic O, if needed.

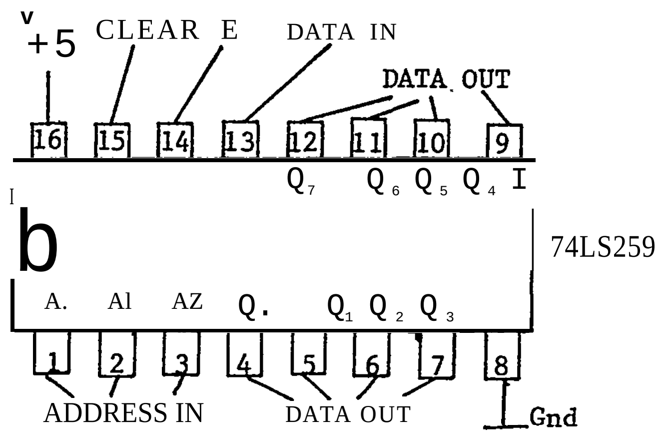


Fig. 9. Eight bit type 74 LS259 integrated circuit device.

Applications of Digital Electronics to Microprocessors

A major application of conventional sequential and combin atorial digital circuits is address decoding and data latching. It is not uncommon for a manufacturing control device using microprocessors to have only 1K(1024 locations) to 4K (4096 locations) of random access memory (RAM), lK to 2K of read only memory (ROM) and six or fewer input/ output (1/0) devices. RAM might more appropriately be called R/W (read/write) memory since data can be read into or read from it. On the other hand, once ROM has been set it is permanent and cannot be altered. If the microprocessor has 16 bits of address, then 65,536,0 (64K) address assignments are available. Usually only a smell percentage of addresses would actually be used.

It is common practice to assign the lower range of addresses to RAM and the high range of addresses to ROM. If our microprocessor system has a 2K MM and a 2K ROM, a memory map (address assignments) might look as shown in Fig. 10. Note that hexadecimal notation is used to indicate addresses.

To implement such a system one needs to decode the address bus to develop a chip enable signal any time the appropriate range of addresses is available. To address 0000_{16} to 03 FF_{16}, address lines A_{15} to A_{IO} (Fig. 11) must be at logic O. This implies that monitoring only the most signifi-

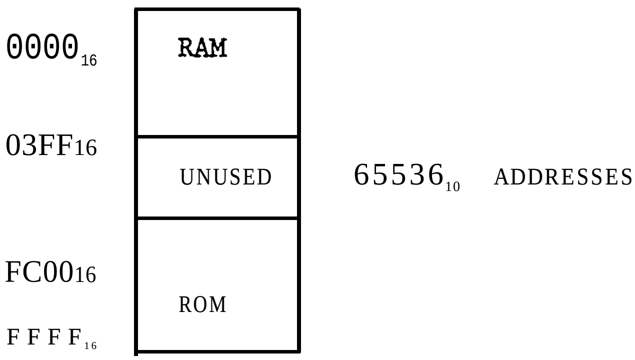


Fig. 10. A Memory map for a small microprocessor system.

cant six bits of address is sufficient to develop a RAM chip enable signal (CE) as shown in Fig. 11.

Note that a control line, the valid address line can participate in the logic so that the chip enable is logic 1 only when the high order address bits are all logic O and simultaneously the valid address line is logic 1.

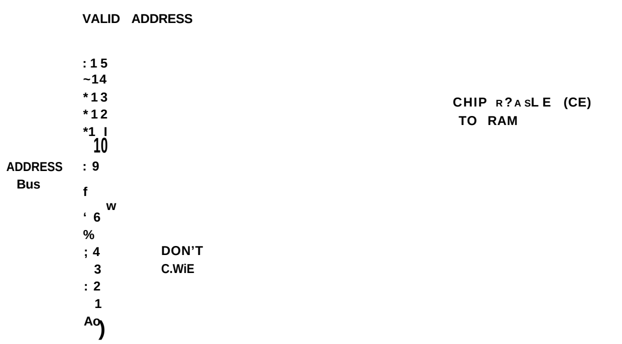


Fig. 11. Partial address decoding for the range 0000_{16} to 03 FF16.

It is often convenient to use combinatorial logic to assign an address to a sequential logic device such as the latch. If addresses above $03FF_{16}$ but below FCOO 16 are unused, we might wish to partially decode the address bus in this range to enable a latch that could be used to retain data present on the data bus. If we choose address 8000_{16} to be the address of the latch, the circuit shown in Fig. 12 might be used to enable the latch at the appropriate time to receive data present on the data bus.

Note that any address starting with 8M as the most significant digit will enable the two latches. This is really of no consequence as the programmer knows to avoid using addresses in this range except when he intends to deposit data at the latch. Of course one can decode the address bus to any extent desired by adding additional combinatorial logic to assign addresses to other devices. Note also that two control lines, the clock and the valid address line participate to synchronize the loading of the latch at the appropriate time.

A second example might make use of an addressable latch as shown in Fig. 13. If addresses $9XX0_{16}$ to $9XX7_{16}$ are set aside for use, the most significant bits can be decoded

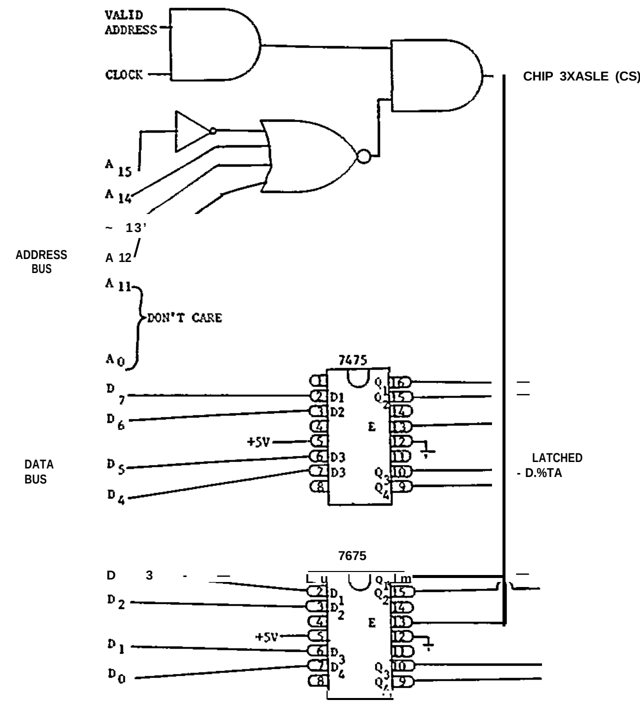


Fig. 12. Partial address decoding to enable two four-bit data latches.

using combinatorial logic and the least significant three bits by the latch address inputs. In this case any address starting with 9_{16} and ending with 0_{16}-7_{16} would address one of the output latches and allow loading the appropriate output bit.

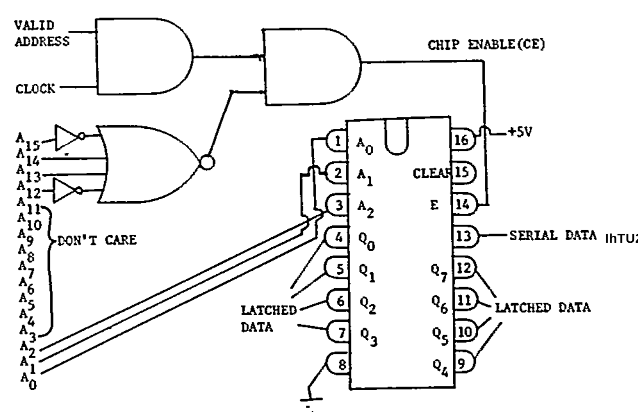


Fig. 13. Partial address decoding to enable an addressable latch.

Time Division Multiplexing

Time division multiplexing refers to a method by which the microcomputer's actions are time shared with two or more tasks to effectively accomplish all tasks in parallel. As an illustration, the human eye's persistence of vision can be exploited in numeric data displays to give the impression of simultaneous data display when in fact the data display

process is a discrete sequence of microprocessor tasks.

Seven segment (or 8 segments if a decimal point is provided) displays are widely used to present digital data visually. Eight bits of binary data must be decoded to illuminate the appropriate segments to visually form a digit. Providing appropriate combinatorial logic to decode and latch the data for each individual display is comparatively expensive. A time division multiplex approach can be used to time share only two data latches with an arbitrary number of seven segment displays and involves relatively simple additions to the programs (software) controlling the microprocessor's actions.

Figure 14 shows the data and address buses connected to two address decoders and to two data latches. The address decoders enable the latches when the controlling program generates the appropriate address so that data placed on the data bus can be held in one of the latches. All corresponding segments of each display are wired to the same output of the 8-bit latch. Each display is connected to ground through a power transistor. If the transistor is not energized by signals from the appropriate bit of the 4-bit latch, the entire display is switched off. At any given time, only one transistor, hence one display, is energized.

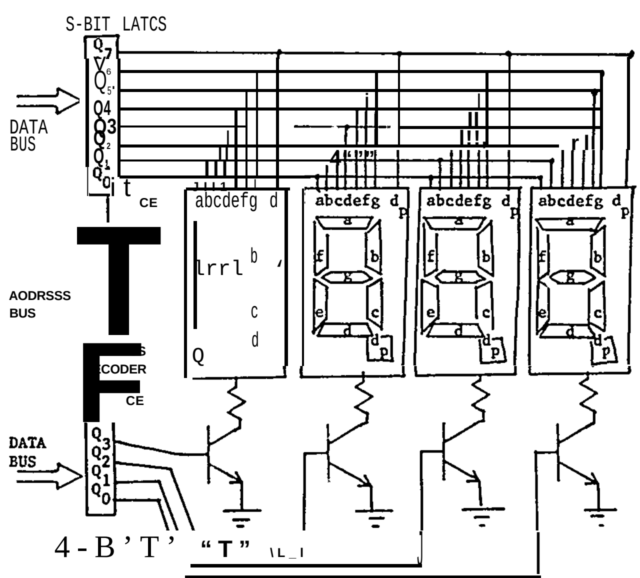


Fig. 14. Time division multiplexing of data to seven segment numeric displays.

The display cycle begins by storing 0000_2 in the 4-bit latch, hence all displays are off. The 8-bits of data corresponding to the leftmost digit are deposited in the 8-bit latch. The program then stores 1000_2 in the 4-bit latch and the leftmost display presents a digit. After a few milliseconds delay, 0000_2 is again placed in the 4-bit latch and all displays are again off. Now, 8-bits of data corresponding to the second from left digit are deposited in the 8-bit latch followed by 0100_2 in the 4-bit latch. Now the second display from left presents a digit. The cycle continues left to right until all digits of the data have been displayed one at a time. At the end of one display cycle the program segment begins again and repeats the cycle starting with the leftmost digit.

Since the microprocessor can easily execute the program to perform a display cycle in a few milliseconds, the number of cycles per second can easily be 30 or more and the eye perceives an unflickering display of all four digits. In fact, using the delays between digits and display cycles, the microprocessor can execute hundreds of other program instructions thus allowing the microprocessor to not only accomplish data display but also to carry out additional functions such as the conversion of analog signals to digital data. The speed of the microprocessor is so great that in spite of the sequential execution of instructions the user is given the impression that all tasks are being accomplished simultaneously. This is merely an extension of the concept of time division multiplexing, in which the microcomputer is time shared with many tasks at such a rapid rate that to the user, all tasks seem to be accomplished in parallel.

Analog to Digital and Digital to Analog Conversion

Electrical signals produced by devices such as strain gauges, temperature sensors, position sensors, and pressure sensors are electrical analogs of the displacement, temperature, position, and force or pressure quantities being measured. Each transducer is furnished with a calibration chart or calibration constant relating electrical output voltage to the physical quantity being measured as illustrated in Fig. 15.

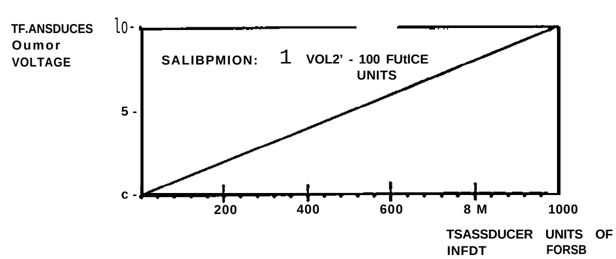
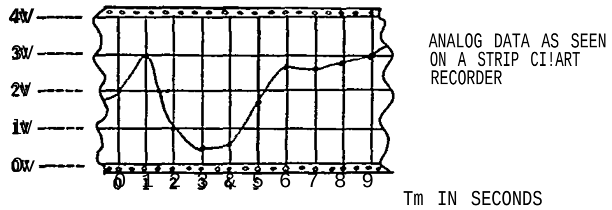


Fig. 15. Electrical calibration of a form transdu~r.

The analog data produced by such a transducer can be recorded directly on a pen and ink, strip chart recorder. More often, one would like to have the data in digital form so that computations could be performed automatically. Figure 16 shows the equivalence between analog data as seen on a stripchart recording, and digital data as represented by measurements taken at periodic time intervals.

Adding analog input and output capabilities to microprocessor systems greatly increases their utility for use in control of manufacturing processes. An analog to digital conversion involves measuring an analog signal at a point in time to produce a digital representation of that voltage, and thus indirectly the quantity being measured. Digital to



TIME IN SECONDS	TRANSDUCER VOLTAGE
0	2.00
1	3.00
2	1.00
3	0.40
4	0.50
5	1.70
6	2.75
7	2.74
8	2.91
9	3.00

DIGITAL DATA TARE?{ AT SPECIFIED TIMS INTERVA2S

Fig. 16. Correspondence between digital and analog data.

analog conversion involves the conversion of a digjtal quantity to a proportional electrical quantity suitable for input to an actuator or other control device.

Digital to analog converters (DACS) are readily available and low in cost. One such device, a type MC 1406 6-bit DAC is shown in Fig. 17.

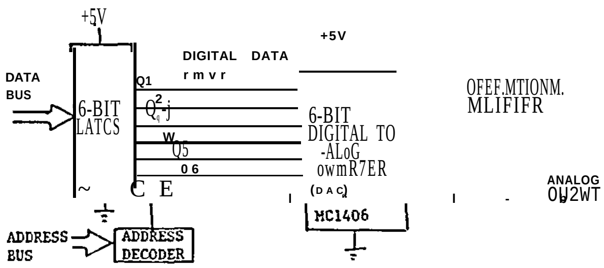


Fig. 17. Six bit digital to analog voltage conversion.

‘l’he DAC converts a 6-bit binary input into a proportional current. The output current is coupled to an operational amplifier to convert the proportional current to a proportional voltage. Since thele are 6 bits of input, there are 2^6 or 6410 discrete levels of output current. If the operational amplifier is adjusted for a O to 10 volt swing between 000000_2 and 1111112, each bit equrls 0.16 volts approximately. Digital to analog converters with 8, 12, and 16 bits of resolution are also available and can be used if greater precision is required. It is by means of digital to analog converters that one indirectly accomplishes the conversion of analog signals to digital data. Conversion from analog signals to digital data requires the addition of a voltage comparator to the DAC as shown in Fig. 18.

The software of the microprocessor generates an analog voltage ramp by successively incrementing the binary value placed in the six bit latch. After each increment, the output of the voltage comparator is checked by enabling a 3-state buffer through another address decoder. When the voltage

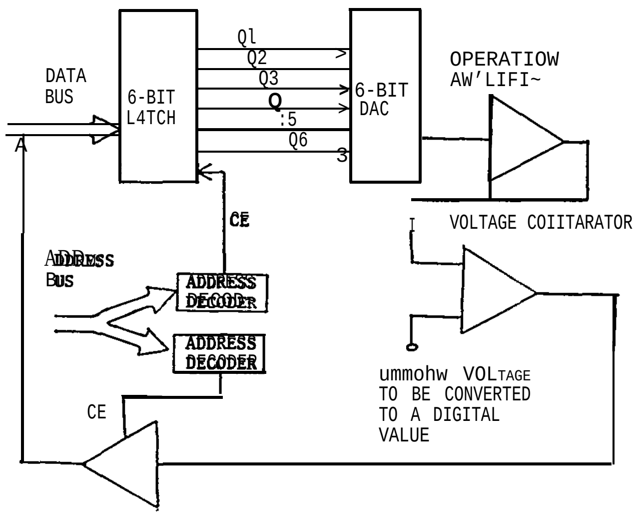


Fig. 18. Analog Voltage to six-lit digital conversion.

comparator switches from logic O to logic 1, the voltage ramp has bracketed the unknown voltage. The bit count in the 6 bit latchis now a digital representation of the unknown analog voltage and can be processed as a digital value. Of course greater resolution is obtained by using an 8 bit, 12 bit, or even a 16 bit DAC in the analog to digital conversion algorithm.

The addition of analog to digital and digital to analog capabilities to microprocessors provides the user with the opportunity to automatically measure quantities of interest, to perform complex computational and decision making operations on the digial quantities, and to respond with appropriate signals to actuate a variety of control devices. Such systems offer very high speed and reliability with the capability of improving future performance with no additional hardware as users develop increasingly sophisticated programs for the microprocessor.

Conclusion

Conventional digital electronic devices add considerable versatility to the application of microprocessor devices to manufacturing control, data acquisition, and machine control applications. An elementary understanding of combinatorial and sequential logic together with partial address decoding schemes results in a satisfactory microprocessor system for a significant number of manufacturing applications. Simple digital to analog and analog to digital conversion is possible with little additional hardware and expertise. Time division multiplexing of the microprocessor among several tasks adds complexity to the programming task, but saves substantially on the number of parts needed for a function such as a data display. When these concepts are mastered, microprocessors can be readily incorporated into the set of alternatives available for control of a manufacturing process.

References

[1] Williams, Gerald E., Digital Technology Principles and Practices, Science Research Associates, Inc., Palo Alto, CA (1977).

[2] Sloan, M. E., Computer Hardware and Organization: An Introduction, Science Research Associates, Inc., Palo Alto, CA (1976).

[3] Osborne, Adam,An Introduction to Microcomputers Volumes I and II Adam Osborne and Associates, Berkeley, Ca. (1976, 1977).

[4] Wester, John G., and William D. Simpson, Software Design for~icroprocessors, Texas Instruments Inc. (1976).

[5] Harrison, Thomas J., Minicomputers in Industrial Control, An Introduction, instrument Society of America, Pittsburgh, Pa (1978).

[6] Texas Instruments Inc., The TTL Data Book, 2nd Edition, Texas Instruments, Inc. (1978).

[7] Lancaster, Don, The TTL Cookbook, Howard W. Sams & Co., Inc., Indianapolis, Ind. (1976).

William M. Marcy was born in Lubbock, Texas, on March 28, 1942. He received the BSEE degree in 1964 and the MSEE degree in 1966 from Texas Tech University. From January 1966 to June 1970 he was employed as an electronic engineer by the US Central Intelligence Agency. In 1970 he was granted a leave of absence to complete the interdisciplinary PhD degree in engineering at Texas Tech University with major emphasis in computer science, systems analysis, and industrial engineering. He received the PhD degree in 1972. He returned to the Central Intelligence Agency in 1972 becoming an engineering branch chief in 1973. In 1975 he accepted the position of associate professor of systems in the college of engineering at Texas Tech University. He currently teaches courses in computer science and industrial engineering. His research interests include technology assessment and energy research. He recently acted as project co-director and principal investigator of the Trans-Pecos Photovoltaic Concentrating Experiment, a 200kWp solar energy system for the Trans-Pecos region of Texas. As principal investigator he had overall responsibility for on-site computer based systems and for all on-site data acquisition.

"THE EXCEPTION PROVES THE NEED--FOR ERGONOMICS"

Donald F. Jones
Chief, Safety Studies Service
Ontario Ministry of Labour

ABSTRACT

Industrial engineering relies heavily on statistical procedures to validate hypotheses ignoring rare, non-conforming data as irrelevant. This paper explores some areas where such "exceptions to the rule" or "freak accidents" which remain after traditional approaches have been exhausted can be resolved through intelligent application of ergonomics.

The exception. . .proves the need. . for Ergonomics! Am I merely playing on the old phrase "the exception proves the rule" or is there a message in this which is truly applicable to our methods of dealing with the interaction of man, machine and environment? It is too easy to latch on to such cliches and use them in situations where they appear to be applicable, even if we do not understand them. If we are to solve problems associated with production, quality, injury, disease and profits, we will likely believe that any exception to our rules will be detrimental. How then can an exception prove *a* rule?

If we revert to another common phrase "as a rule" we begin to see the light since this phrase indicates its own imperfection and we have the fact that anything which is correct more than 50 per cent of the time, is legitimately a "rule". Utilizing this argument we can say that rules are made by man in an attempt to describe the "laws" of nature. Whether we believe that these laws *are* decreed by a divine being or are merely the development of evolution through statistical "trial and error" is immaterial to the validity of the statement. The belief that "the exception proves the rule" merely indicates that we are dealing with man's attempt to formalize and verbalize a natural law and that our attempt to do so is imperfect.

Once we have done this we can recognize that many, if not all, of the scattered dots that appear on a graph depicting our experimental results and which do not fit our theoretical curves and hypotheses may be as accurate as those which do. What we haven't discovered are the right words and symbols *to* describe the law. Until we do, we must recognize that these variations may signify something as important as the average, mean, standard deviation or whatever statistical procedure we decide to use.

This raises the question of whether we should be attempting to find specific or general requirements suitable to the greatest number of people or if we should have several categories. This is further reinforced by the fact that treating all human components in isolation ignores the reality that man is a combination of three persons within a single body. These are the mechanical man, the biological man and the emotional man. When working together they are capable of amazing feats but when out of synchronization you never know what will happen. It is only through multi-disciplinarian approaches, such as Ergonomics, that we can bring the knowledge of all disciplines together to fully understand how best to design systems to achieve the greatest benefits from this composite man. When we attempt to do so we realize that there are some things which may be suitable to all persons but there are others where variations in the mechanical, biological and emotional components make it necessary to select narrower ranges into which we can place people which are more compatible to the situation. Even here, we must understand the person's background and capabilities to determine what training or other features are necessary *to* obtain the best fit.

Our attempts to do this generally involve adjustments of heights of chairs, and other such attempts to modify the system to suit individuals. In so doing we often measure the person and try to determine what is the optimum or maximum without recognizing that even for that person there is no posture or operation which is right for an eight hour shift. In reality, changes in emotion, fatigue and internal chemistry necessitates changing posture and if we do not provide a system in which the person has freedom to adjust to compensate for postural strain and other such situations we have not done our job well.

In attempting to find out what is best for a person, ignoring the fact that what is best varies not only between persons but with time, we fall

into a trap which has been described to me as the "folly of epidemiology". Anyone who has lived in this century recognizes that it is through epidemillogy that most of our advances in public health care have come. To question its validity is almost sacrilegious. I am not about to question its validity any more than I would question the validity of using averages, percentiles and other such statistical procedures. . . where appropriate. lJhat I do suggest is that its validity is not a natural law but is a man made rule with exceptions in which the treatment does more harm than good.

If we could apply the knowledge pained from epidemiology to those people who would benefit from it and use a different procedure for those who do not respond we would get results far beyond what we can today. This frustration is expressed by toxicologists who point to experimental data indicating that the biological changes resulting from the presence of a certain chemical can, under certain circumstances, cause cancer. They, therefore, suggest that precautions should be taken related *to* any such chemical to ensure that conditions are not reated which in the presence of other variables (including time) will cause cancer in a percentage of the persons so exposed. They draw attention to the fact that conventional epidemiological studies dealing with a total population in which many variables exist and cannot be isolated obscures the results to the extent that it is many years before it can be proven that there is a significant problem requiring attention. Effectively they are saying that if there is a problem involving a chemical or other hazard we should be able to isolate this and make pronouncements as to the precautions to be taken without first studying it as part of an effect involving every company or person using the product. what the toxicologist recognizes is that there are so many other variables coming into the mix that they may obscure the result thereby delaying necessary action.

This apparent discrepancy in thinking between epidemiologists and toxicologists has a direct [,.];:Illel in the occupational safety movement in that some people believe that we must look at the net accident rate or severity when determining the validity of our program whereas others believe that if we focus our attention on eliminating all scratches we will automatically prevent the worse situations from developing. I suggest to you that the person who concentrates on the net effect may be missing important variables. On the other hand, the one who concentrates all effort on preventing even the minor scratches is like the housekeeper who runs arouud trying to catch all of the dust before it lights on the furniture. This utilizes time and energy which could be more constructively used. We could, of course, quote Pareto's law to the effect 80 per cent of the problems lie in 20 per cent of the situations. But this, again, ignores the exceptions and I, therefore, suggest to you that if we are to succeed we must continue to do what we have been doing in trying to find rules and descriptive models which provide the best fit and then utilize our talents to find out why some things do not fit and what we should do about them rather than merely considering them as statistical flukes, freak accidents and other such lame excuses for not attempting to find the truth. Once we start looking *at these* exceptions we will better understand what Douglas Bader meant when he said that "rules are made for idiots to follow and wise men to use as guides". For those who do not know Douglas Bader he was a Royal Air Force pilot in World War 11 who flew combat aircraft without legs. He was one of the many exceptions that proved the need for Ergonomics and if you don't believe it you might search your library for information on him or on any of the other supposedly crippled people who have overcome what others would consider to be impossible odds.

So far, I have talked in generalities so let us take a few specifics of how ignoring individual talents and weaknesses has affected the operations of an industry or the lives of its employees.

Case #1 - After pressures from women's groups a company which had formerly hired only male employees to work on the assembly line agreed to try ten women. After a short period they showed that the women could not produce the required work ***on*** this line. Nhat was forgotten or ignored was that any consideration given to the design of the assembly line was based on the type of people who had been working on it previously. Over a period of time any adjustments bad ensured that the demands were compatible with the type of males normally hired by that company for that type of work. It had nothing to do with the capability of a woman to work on an assembly line. If the line had developed over the ***years*** with female employees any attempt to place male employees in this situation would likely have resulted in an equivalent reduction of production. It would appear that those who suggested that women were incapable of working on *an* assembly line had not read the story cf the ancient Amazons who removed a breast because it got in the way when they were using a bow and arrow for hunting or warfare, This is not to suggest support for such actions but to utilize an ancient story to emphasize that an operation designed for males may be incompatible with most females or vice versa. A more recent example is a woman who was not producing adequately in an operation which seemed to be suitable ***to*** most other women engaged by the same employer and it ***was*** not until another woman asked her problem that it was discovered that she was a little shorter than most and somewhat more endowed with female features to the point that the design of the work site created discomfort which inhibited work. The simple solution of raising her stool a few inches changed her from a liability to one of the assembly line's best assets.

Case #2 - A company manufacturing batteries took all precautions normally required to prevent lead poisoning including separate lunchrooms, change of clothing, showers, ventilation, blood tests and

whatever else might normally be necessary to prevent the employee from inhaling or otherwise being exposed to the lead or in carrying it outside of the work place where other persons could be exposed. Nevertheless, an employee, after working for a short time, was shown through blood tests to have a severe case of lead poisoning. After exhausting every other possibility of exposure someone finally recognized that this individual had the habit of nail biting thereby nullifying all other precautions. If it had not been for the periodic blood tests the situation would not have been discovered until it was more severe.

Case #3 - A building appeared to be developing some cracks in the walls and a consultant was brought in to determine if there was anything wrong with these walls. After careful examination and checking the drawings of the footings, wall thickness, etc. this consultant said that the walls were strong enough that they could build a second storey on top and that cracks must be from expansion or shrinkage caused by severe temperature change. The following winter the building collapsed killing several people. On investigation it was found that the cracks had nothing to do with the wall strength but were related to outward pressure which had been developing through a poor glue job in the wood trusses supporting the roof. Even at the inquest some of the experts who had investigated the failure pointed to inadequacy of web members of trusses (paying little attention to the glue) even though there had been no initial failure in these members.

Case #4 - An employee lost fingers on a punch press. The investigation could find nothing wrong with the press. The only apparent possibility appeared to be that the press had double tripped. The company initiated a more frequent replacement schedule for those parts which could cause such a problem. The speed of the press as related to the employee's reaction time and the effect of such a traumatic experience on the employee's short and long term memory were ignored. In introducing psychophysical and other data it was shown that another and more plausible reason for the injury existed and that the action taken could, in no way, have prevented ***it*** whereas a change in the guarding mechanism or of the speed of the press could have. They had operated this machine for many years without a problem. It may, again, go for many years without a problem but the situation did arise in which it did nOt fit the normal rule and those involved in the investigation did not have sufficient multidisciplinary knowledge to look at it as would someone fully trained in the field of Ergonomics.

The foregoing are merely a few examples selected from my more than 28 years involvement in this field either from my own investigation or from my attempts to learn from other experts in the field. Two of the above-noted examples are based on material from my good friend Dr. E. mastrormatteo who is now with INCO Limited after spending many years in Ontario's occupational health and safety program and a further period in charge of the occupational safety and health effort of the International Labour Office in ***Geneva.***

At a recent conference on sociology, a reference was made to someone who had said "I have lived a long time and never seen a problem solved". Some of the people, at the conference, were quite upset at such ***a*** statement but, as for myself, I must admit that in all the years I have been with the Ontario Ministry of Labour, I have not seen a problem solved. I have seen some improvements and I have seen us constantly re-inventing the wheel. I have seen individual actions taken which have prevented injury, disease and material loss, but the solution to a problem goes much deeper than local and temporary successes. I suggest that this is ***not*** only true but that the reason is based on our traditional approach of believing that we can solve problems without having a full understanding of the complex interactions between the various forces acting on the man/machine/environment system. As an example, I suggest to you that in the many years that we have recognized the hazards of lead, benzol, zinc and asbestos including the need to limit exposure ***to*** these substances, we still run into situations where there is inadequate ventilation, persons remove their protective equipment or bite their finger nails. To study the health effects of substances, without taking the supplementary step of finding how to convince people of the actions they should take and determining the effects of substitute actions and substances is merely the first step in resolving our problems.

If you look at the people around you, or think of yourself, you will see a human being which consists of the three main components mentioned earlier. If we try to do something related to one of these we automatically affect the others, either positively or negatively. Attempting to solve a problem of one will not necessarily solve our true problem but may have adverse side effects. We should be able to look at statistics, which will give us the answer, but the statistics we have today are of little use beyond saying that there may be a problem. We can utilize information from news media, inquests, the general public or our field staff in telling us of specific cases which concern them but this is not enough to warrant more detailed studies since we would be unsure whether these were isolated cases or were really problems warranting attention.

Without downgrading the effect of isolated reporting, ***it is*** recognized that to spend money on a study, particularly one which is not **seen as** important by those who have control over the funds, needs support of something beyond an isolated case. As a result, I have done some work in an attempt to determine the usefulness of enforcement and the validity of existing statistics. This involved a study of various provinces and states, several years ago, which amongst other things clearly indicated that reporting injuries on the basis of lost **time** didn't give us the answer we were seeking.

I found companies with a supposedly high accident rate where the worst injury involved an employee who ran off the ball field onto the grass in a break period, tripped over a garden hose and broke an arm. This company was on the verge of an increased compensation assessment. Another company which waa pleased with its total loss control program and supposedly had an excellent record, had a single loss time injury in the previous year which was an amputated finger. I cannot help but wonder whether this second company which had an excellent health benefit program and where no forms were necessary to be filled out if you were off sick, but where extensive reporting and forms were necessary for a work injury was truly better than the other one or if motivational factors were more significant in lost time than the extent of injury.

As a further step, I am working with the Research Branch of our Ministry to obtain a breakdown of information on employees receiving pensions for partial or total disability, from the Workmen's Compensation Board. This may get us a little closer to finding out what is really happening to people but we must recognize that the Compensation Board can only report injuries or diseases which are considered and accepted as compensable. Perhaps, we should be looking a little further to obtain information from hospital records or from a broader health insurance plan such as Ontario's O.H.I.P. We might also look at other jurisdictions to determine if they have a broader breakdown of the types of injuries which result in long term disability and try to compare their records with ours to determine the true need of gathering the supplementary information.

Whether you are exposed to a toxic substance, look at an attractive member of the opposite sex, or a beautiful sunset you feel some emotion which results in the release of chemical in your system.

Chemicals may cause a psychological or emotional effect or vice versa regardless of whether generated externally or internally. There seems little doubt that a psychologist would have a useful input. Since many of the emotions or the release of chemicals result in bodily movements, whether observed directly or merely through increase in heart rate or contraction or relaxation of muscles, we can see the importance of understanding how the body's mechanical components work and that is where the physiologist and the engineer start to come into the picture.

An alternative or complementary person is the ergonomist. This is the person who knows enough about the various disciplines included in the physical, biological and behavioral sciences to put them all together and better understand the complex interaction of man with other men, machines and environment. His purpose is not to change the behaviour of man but to understand capabilities and interactions so systems can be designed for people to operate in a manner to minimize injury and disease utilizing the habits and capabilities which they already have. In addition, this person should be able to recognize the situations where such a perfect match cannot be achieved thereby helping determine criteria for selection of individuals to fit the system or to determine the type of training necessary to provide for a broader selection of people who can operate safety in the environment as created.

In closing, I must emphaaize that what I have said today comes from exposure ***to*** both field experience and to a lot of wonderful people throughout this continent and more remote sections of this globe who are all striving to find the ***answers to one or*** **more** parts of the very complex problem of bringing our currently inadequate rules closer to describing how man can operate effectively and safely within the systems to which he is exposed. Until the answers ***are*** found, we must recognize that there are many exceptions which prove the need for Ergonomics and any other discipline or combined discipline which will help us understand and avoid what we now naively refer to as "freak accidents" or "acts of God".

BIOGRAPHICAL SKETCH

Don Jones, Chief of Safety Studies, Ontario Ministry of Labour. Mr. Jones is currently involved in re-examining occupational safety programs and concepts in an attempt to discover ways to reduce the number and severity of work injuries. Projects under consideration cover such ***varied*** topics as back injuries, heat stress, machine guarding, motivation and program effectiveness. He is a member of several professional associations including A.I.I.E., H.F.S., A.P.E.O. and A.I.H.A. His role has included all aspects of safety including preparation of legislation through enforcement, education, consultation, and administration. His stimulating and sometimes controversial views have appeared in many publications including the AIIE Journal.

PRODUCTION ROUNDTABLE - HOW TO INCREASE PRODUCTION

INDUSTRIAL RELATIONS CONSIDERATIONS

W. Colebrook Cooling
Director, Industrial Relations
Engelhard Minerals and Chemicals Corp.
Iselin, New Jersey 08830

INTRODUCTION

I appreciate the opportunity to comment on productivity matters representing the Industrial Relations function. Productivity matters should not be approached from the viewpoint of a flood of behavioral emotions, but should be based upon "hands on" experience. My comments are based upon experience in manufacturing and chemical operations as an I.E., a General Manager, and presently in the Industrial Relations functions.

You will also note that my considerations are with the basics. It is my opinion that there is more time wasted in management today making projects and procedures as complicated as possible rather than accomplishing the mission of "More good units per hour, from each loyal employee, on time".

Whether a day work approach is used, or whether an incentive program is involved, the approach is identical. With either situation, there is no difference in the techniques used and the goals are:

1. proper engineered production standards based on the 100% level
2. high standards coverage
3. each employee working on standard
4. accurate time reportage and production counts
5. fast response employee performance date for corrective action by supervisors
6. help the employee to produce to standard or above

Considerations that will assist in accomplishing the above follow.

MANAGEMENT MUST UNDERSTAND THE MISSION

I worked for a large corporation as a Corporate I.E. The accounting group sponsored standard cost training consisting of eight sessions of two hours each for supervision. The objective being to assist supervisors to understand the necessity of meeting production standards *to* control labor costs of manufacturing. Despite the expertise of corporate training, the standard cost manual, the slides, the well prepared text and the resulting lectures, this training project was a waste of time. The audience was bored, the language lias not that of production, and the participants did not understand the mission.

Figure #l is the last page of a booklet titled, "Either OR with REGARD TO LABOR EFFECTIVENESS". This is a summary of the previous seven pages and the remarks for this page are simply:

"We hire Direct Labor. They either work on indirect charges or direct work. Indirect charges are either downtime or some indirect activity that is not work or an individual unit and is overhead. We want to locate these indirect items and serve to Direct Work. Direct Work is either not measured or on standard. If the work is not measured, we cannot judge an employee's performance . So, let's get this direct work on standard. When *we* have a standard, our employees either produce to standard or they don't. Our job is to counsel and work with employees and help them make standard. At this point, *are* are doing a proper job of running the factory."

To summarize...

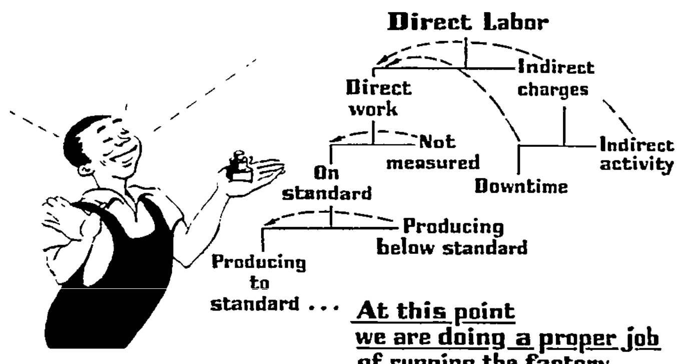


FIGURE 1

So, 15 or 20 minutes of plain, basic facts that supervisors understand replaces eight two hour torture sessions.

My point to all I.E.'s is don't abdicate your responsibility in making sure that every function of management understands the mission, in particular, the front line supervisor who "makes or breaks" your efforts.

INSURE PROPER ADMINISTRATION OF STANDARDS AND RELATED PROCEDURES

You have all read the headlines regarding wage incentive failures or day work failures resulting in work stoppages, abandoning the system, or whatever, resulting in higher labor costs. Well, the system did not fail, the instance was a failure of management. I.E.'s cannot leave the administration to every Tom, Dick, and Harry that comes along, whether in front line supervision, accounting, industrial relations, general management, and so forth.

Figure #2 is an example of a route to go. Take the labor agreement provision or the standard procedure and define "intent" and "administration". Don't expect people to read, review stimulating discussion, this material in seminar groups.

Figure 2

3. An incentive provides an opportunity to increase wages, but it is not always possible to guarantee this opportunity. The incentive portion of the total hourly pay is payable only when actually earned by production. Machine breakdowns, material shortages, delivery errors, transfer to other jobs, and similar events may act to limit earnings opportunities. When this happens, the employee will be paid as outlined under Section 1 Non-Standard Production. The Company will attempt to keep these delays at a minimum.

Intent:

1. To establish that the incentive plan is not a guarantee to increase wages.
2. To provide that incentive payment will only be paid when earned by quantities produced in production.
3. To specify that non-standard events such as breakdown, delays, transfers and so forth will occur and will limit earnings opportunities.
4. To provide for proper payment of the employee during those periods when the employee is not afforded incentive opportunities.
5. To pledge that the Company will manage properly to attempt to keep non-standard periods to a minimum.

Philosophy:

There may be a view point in the plant that incentive operators should always earn incentive pay. This is only true if an employee expends incentive effort. For example: An incentive operator who expends 120% skill and effort as compared with the SAM rated films should receive comparable incentive pay. The contract does not agree on incentive payments, unless there has been a skill and effort output above normal in which instance the employee shall receive comparable incentive pay.

The problem also must be faced that events will happen which will necessitate an employee working without a standard. This will, of course, limit earnings opportunity and the foreman must make every effort to either remove the cause of non-standard production or move the employee to work that is on standard as we have pledged to keep these delays at a minimum. In every instance of non-standard production the employee not only loses incentive opportunity but the Company's costs are increased as a result of some deficiency.

Administration:

1. When the foreman is notified by an employee that the employee has a non-standard situation, such as machine breakdown, material shortage, no standard on job, and so forth, he shall approve the employee's time card at the time the event occurs, noting the cause, and applying the proper code on the time card.
2. The foreman at this point, being informed that the employee is losing the opportunity to work on incentive, thereby increasing the Company's cost, should immediately act to correct the condition by removing the cause of the problem or if this is not possible, removing the employee to another incentive operation.
3. The foreman should also note the time that the employee goes back to incentive work to verify that time charged to non-incentive work is accurate.

Include the peripheral functions, accounting, industrial relations, in addition to the front line administrators of production standards, the supervisors. The objective of this training is to provide uniform understanding and administration to enhance the credibility of management. This training will generate positive, consistent approaches to questions and problems in the application of production standards. This approach is most necessary with regard to the Industrial Relations function, most of whom are bombarded with behavioral nonsense.

POSITIVE LEADERSHIP

Leadership cannot be mentioned without quoting one of Phil Carroll's many remarks relating to production standards. Phil always maintained, "75% is dealing with people and 25% is the technical side." I would like to believe that I.E.'s reserve enough of that percentage to club data processing into accepting fast response reporting methods that not only pay employees, control inventory, make standard cost comparisions, but assist the front line administrators to know "what's going on in the factory?". Despite some of the academic "do gooders" and the behavioral crowd, we still have to manage the operation.

A practical method to train supervisors in leadership relies upon the union manual used to train union representatives in leadership. Figure #3 is a page from such manual altered to fit the instructor's needs of a front line supervisor.

THINGS YOU NEED TO KNOW TO BE A GOOD ~~JOB STEWARD~~ SUPERVISOR

Know Your Contract

—Study and read your contract carefully
—Understand how each provision applies to special conditions in your shop
—Discuss contract with ~~union officers and other stewards~~ INDUSTRIAL RELATIONS Discuss at meetings
—Carry a copy of it at all times
—Refer to it on all occasions
—~~Most~~ Some grievances ~~will~~ may be contract violations

Know Your People

—People aren't all alike. Different people have to be handled differently
—Some people will give you the full story on a grievance, others won't
—Some workers have a good steady work record that you can use as an argument when talking to the ~~foreman~~ UNION REP, others don't
—Some workers have home problems that affect their work, others don't
—Get to know the people you represent and you can take these differences into account

Know Your Department

—Know all the workers in your department—name—address—telephone number—badge number, etc
—Know the wage rate of each worker
—Know all job classifications
—Know the seniority of each worker
—Know all operations in the shop

Figure 3: [illegible] for supervision from the Manual for [illegible] AFL-CIO-CLC Shop Stewards with [illegible] alterations.

Best training technique available. These manuals are well written and the union representatives are well trained. Use the manual of the Union that represents your employees. Management might just as well learn from the competition in leadership.

Improvements in productivity, whether method changes, process changes, equipment changes, the application of production standards, and the administration of work measurement policies and procedures will not be totally effective without responsible leadership.

A Company may have competent and productive staff functions, however, everyone must recognize that front line supervision is responsible to install, to train, and continue to administer the improvement. To insure the success of the I.E. function, insure that the leader of the employees is the front line supervisor.

MAKE CERTAIN THE SUPERVISOR CAN DO HIS JOB

Equip supervision to learn of the excess cost situations in time to correct. A typical situation, existing in many plants, occurred in a plant in Rochester. Time and count data was expedited from the production flow to the computer. Supervision was not supplied with immediate reminders that fast response corrective actions were necessary. There was at least a three day lag for information *on* a daily basis and a *weeks* lag for the weekly summary. "Pepper" Kulpinski, a former minor league ball player, was the Plant Manager and called the weekly summary his "box score". "Pepper" had a problem, all his data was after the fact,there was no means of highlighting excess cost problems, while in progress, in order to take immediate corrective action. "Pepper", from his baseball management experience, knew the "box score" turned out good or bad depending upon management moves as the "game" progressed. So, the "red rack" came into being. Figure #4 is the "red rack".

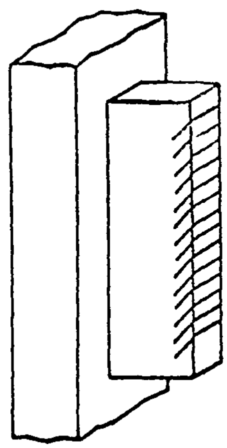
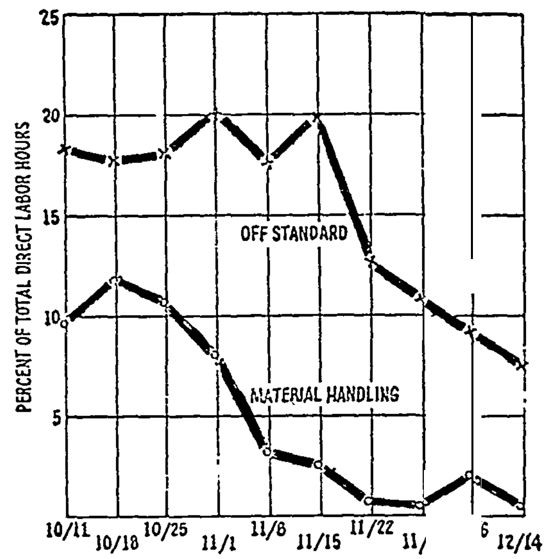


FIGURE 4

Employees who went off standard were instructed that after clocking out through timekeepers *to place* their card in the "red rack". Anyone going into the department, whether chairman of the board or janitor could immediately locate excess cost situations. Everyone could determine "what's going on in production on an exception basis. The supervisor's excess cost problems were highlighted. He could contact staff help when necessary and Figure #5 illustrates partial results, which made "Pepper's" box score look better.

FIGURE S



The baseball manager maneuvers during the game and similarly the supervisor must take corre'ctive action while the work is underway. Phil Carroll wrote this up in one of his books as did the MA and several others. "Pepper'' was the co-author of an article titled, "Cost Control Takes Guts" which drew a lot of reader response.

Don't let data transmission methods, the computer, timekeepers, or anything else come between the supervisor and the employee. Never mind how simple the cure is, but achieve a fast response to locating productivity mishaps.

HELP THE SUPERVISOR HELP THE EMPLOYEE

The I.E. should not develop standards, issue the standards to the floor and walk away. In a Massachusetts operation, a day work installation was in operation with proper standards, the same controls in effect that one would require with wage incentives, and the I.E.'s had agreement with the plant that when it could manage a day work installation, the plant would earn the right to an incentive installation. Agreement had already been reached with the Union as to the necessary provisior in the labor agreement,

After production control was manicured, a maintenance control method installed, a tool control system was in operation, timekeeping methods were installed and the supervisors and union representatives received training in the intent and administration. The right to an incentive operation was *earned* by that plant through the ability of the plant to maintain standard conditions, having high coverage, both contributing to the opportunity for a person to earn incentive pay.

The standards were not "dumped" into the plant, I.E.'s were present each shift to observe work situations, report recommendations to the superviso the supervisor immediately counseled the employees

The efforts of all resulted in an increase from about 65% average efficiency, 125% average in a two week period. Since it is looked upon as almost an industrial crime in some circles *to* use money to motivate, you may regard the 25% increase in pay as a reward rather than motivation. Figure 6 is extracted from the I.E. log in a department during the installation stage.

FIGURE 6

The third day on incentive in the welding Section again showed a marked increase in production

The Items that needed q mangement attention are:

1. The night shift continues high on downtime. The average of 15% downtime includes 6.$8 hours on rework necessitated by poor work of the employee as noted in item 6 on report of August 10. one employee reported 4.74 hours waiting for tool change.
2. one employee on the day shift continues at 52% efficiency. The employee is being councilled.

The following production improvements were noted for August 10, 1960.

1. Day shift non- incentive time is down to a new low of 4%.
2. The day shift efficiency has increased from Tuesday, s overall efficiency of 103% to 107%.

Note: Elinination of the inefficient employee on the day shift would have increased the overall average to 117%.

3. The night shift efficiency decreased fron 95% to 89.5% Jue to return of an inefficient employee to the group.
4. Three employees on the day shift have increased production over Tuesday:
   a. R. MacKinnon increased production from 644 pieces/hour to 685 pieces/hour.
   b. L. KelIy increased production from 874 pieces/hour to 1058 pieces/hour.

   Both of the above employees were on the Filtors job,

s. Production increased again on the IBM paddles.
   a. L. Hatten increased production from 327 pieces/hour to 355 pieces/hour.
   b. L. wilson of the second shift increased production from 326 pieces/hour to 362 pieces/hour.
6. R. Gailey, foreman, and R. Marsh, Quality Control, have been checked and both report a maintenance of quality level on all jobs but the lBM paddle. The IBM paddle quality has markedly increased.
7. Cole Cooling concurs that the operators in the Welding Section are working at an incentive pace comparable with carnings.
8. It is essential that production control install man and machine loading in the Welding Scction to avoid running out of work on both the day and night shift.
9. Production is checked by the timekeeper at start and finish of each employee's. production by meter reading. Meter readings are furher checked daily by scale count.

Buy Shifit			Night Shift		
MacKinnon, R.	108	7.76	Wilson, S.	103%	8.90
Belanger, I.	126%	7.76	Mitchell, R.	72%	2.82
Deters, L.	125%	7.23	wilson, L.	117%	9.50
Kelley, L	119%	7.75	Dargis, F.	70%	9.50
Hatten, I.	125	7.76	Bouchard, P.	55%	3.12
Bennette, D.	52%	7.65			

CONCLUSION

We have touched briefly on

1. training to understand the mission
2. proper front line administration
3. positive leadership
4. insuring that supervision does the job
5. helping the employee to produce

In my opinion, the management time used to insure that the above considerations will become effective is insignificant. By simplifying administrative and control techniques, the time to train is drastically reduced. You are the loser, your good work is misused, when you complicate the basics, thus interfering with the continuing objective of increasing productivity.

BIOGRAPHY

W. COLEBROOK COOLING is Director of Industrial Relations at Engelhard Industries Division, Engelhard Minerals and Chemicals Corporation, located in Iselin, New Jersey. He is an Industrial Engineering graduate from Pennsylvania Military College and has an MBA in Industrial Management from Temple University.

Mr. Cooling worked at Uniroyal as an Industrial Engineer and at Atlantic-Richfield as a Maintenance Industrial Engineer. He was Corporate Manager of Industrial Engineering at International Resistance Company and at Engelhard. With American-Standard, he was a Corporate Consulting Industrial Engineer and then returned to Engelhard as a General Manager.

Mr. Cooling has served the Department of Defense, Properties and Installations as a consultant on maintenance matters and participated in the Ordnance Top Management Seminar at Rock Island Arsenal on several occasions. He also lectured for the Wharton School Refresher courses and taught in Rutgers University Extension Division and at Temple University. His work in the field of Industrial Engineering in manufacturing and maintenance has been recognized in the form of the Professional Manager’s Citation, the Advancement of Management Award, and he is the first recipient of the Phil Carroll Award, all from the Society for Advancement of Management in which he is a Fellow. A Fellow of the Royal Society of Arts and an active member of the IMS and the AIIE, he is also a member of the Commercial Panel of the American Arbitration Association. In recognition of his combat infantry service, an honorary degree in Military Science from his alma mater was presented to him.

Over 100 of his articles have been published and his papers are in the proceedings of over 15 national management conferences for various professional organizations. He is the author of “Front Line Cost Administration”, Chilton Publishing Company, “Low Cost Maintenance Control”, AMACON, and of three chapters in the current Maintenance Engineering Handbook”, McGraw Hill. The AIIE has *recently* published Colers arbitration play, “Arbitration Presentation”. He has presented over 100 seminars relating to increasing productivity in maintenance and production in the U.S., Mexico, Egypt, Kuwait , and Canada as well as many seminars on industrial relations matters

Set a goal, then go for it!

ROGER L. KIRKHAM, P.E.
American Training Alliance, Salt Lake City, UT

Productivity is a function of output/input. If significant, long-term improvement in productivity is to be realized, it must start with management effectively focusing on output–the desired–expected results.

Draw the bullseye first

One day our hero climbed off the train in an old western town. The first thing that caught his eye was a neatly drawn bullseye on the side of the fence in front of him—with one bullet-hole, dead center. He didn't think much about it until he wandered into town. All over the sides of buildings and fences were bullseyes with one bullet-hole, dead center in each of them.

His first thought was: "They certainly do a lot of target practicing in this town. And whoever's doing it is a very good shot! One bullet-hole, dead center every time."

This piqued his curiosity, so he inquired around town as to who the marksmen were. Nobody in town seemed very impressed with the whole thing. He came to find out it was the town idiot who was doing all the shooting.

He decided he had to see this guy, and so he hunted him down and asked him how he was able to hit the bullseye dead center every time. "Oh, it's very easy," the idiot answered. "You shoot first, and draw the bullseye after!"

Too often this shooting first and drawing the bullseye after occurs on our jobs. We get really busy being busy, and then try to draw bullseyes to identify what we should have accomplished—or what we could have accomplished–or where we're really supposed to be in terms of getting the job done. Drawing the bullseye first focuses efforts and resources on desired results.

Roger L. Kirkam, P.E. is president of the American Training Alliance, a company which specializes in training and consulting in technical writing and management. He is author and co-author of over 30 publications, and he teaches part-time at the University of Utah as adjunct assistant professor of industrial engineering. Kirkham is a senior member of AIIE.

Success for a manager

Effectively focusing expected results doesn't come naturally, because all our lives we're taught to keep busy. Management, however, is accountable for *results—not* effort, *getting the job done–not* trying hard. The effectiveness of a manager is gauged by how well his organization gets the job done. His success as a manager depends on how successfully his subordinates achieve desired results. Therefore, the manager's job is to help his subordinates be as successful as Possible in achieving expected results.

But in order for a subordinate to channel his efforts and expertise effectively, he must have a clear, complete understanding of what results are expected, what bullseye he should be aiming for.

Detroit Edison's bullseyes

About two years ago, AJ. Benes, of the Detroit Edison Co., stated that his company has over 10,000 employees, a plant investment approaching $4.7 billion and yearly revenues of about $1.5 billion. It serves over half the people in Michigan with electric power. A few years before, the company was faced with growing pressure to improve productivity. Mounting public opinion expressed the following: Cost-plus mentality; fat cats with automatic profits and no risks; they yell for help instead of getting their ship in order; the only improvement action they take is when they're forced into it.

The company decided it needed to do something significant, something to turn the company around. So it decided to draw the bullseye first. The company embarked on a productivity improvement program by establishing productivity measurements for job positions at all levels. Department heads were expected to define their purpose and then establish measurable criteria by which the output or results coming from the departments could be evaluated.

Detroit Edison decided that the best expert on how to do a given job was the person doing the job. Rather than bringing in outside consultants to define their expected results, the employees themselves helped establish their own criteria. As a result, the company had no objections from the union.

The results of Detroit Edison's program are impressive:

- ☐ Specific management objectives are being used.
- ☐ Training needs, bottlenecks and improved procedures have been identified.
- ☐ Accountability has increased.
- ☐ Scheduling is maximized.
- ☐ Throughput has increased.
- ☐ Workload has been leveled and equalized.
- ☐ Productivity measures are used as part of individual job reviews and salary administration.

Focus on expected results

Focusing on expected results is like making New Year's resolutions: just thinking about it doesn't get much done. The expected results must be written down. This statement of

0019-8234180 [0300-0050$02.00/0

expected results becomes the bullseye, the objective to be achieved.

The following four ingredients of a good objective will focus efforts on expected results.

Objectives should be stated in terms of expected results. This statement answers the question: "If efforts are successful, what will be the results?" The statement of an objective should establish a criteria against which results can be measured.

Comparing this to a New Year's resolution, I might say: "This year I'm going to be a better husband." That's a statement of the expected result that I'll be a better husband. However, as most wives will point out, that's nice—but insufficient. The question arises: "How?" eg., how will I be a better husband? The second ingredient for a good objective is needed to answer this question.

Objectives should be measurable. The objective should be stated in terms of a measurable criteria by which we can know when the objective is achieved. For example, I can make my New Year's resolution measurable by stating: "This year I'm going to be a better husband by helping my wife with the dishes." This statement provides a measuraable criteria which determines whether or not the objective has been achieved. Industrial engineers are particularly trained in establishing and monitoring measures of productivity.

However, my wife still isn't satisfied. She wants to know how often and for how long this miracle of a resolution will occur—which is provided by the next ingredient of a good objective.

Objectives should be stated in terms of a time period. Where applicable, this time period should be in terms of *duration* and frequency. This provides milestones by which progress can be measured and forces emphasis on results rather than on being busy. Adding a time period to my New Year's resolution, I might say: "This year I'm going to be a better husband by helping my wife with the dishes—every night until I die." This provides a time frame both in terms of duration and frequency. However, there's a problem. While this promise may sound wonderful, it isn't very realistic. It is impossible to hold someone accountable for results which cannot be obtained. Unrealistic objectives. therefore, result in people being held accountable for how hard they tried, or how busy they've been. But people aren't hired to be busy. They're hired to get results. Therefore, the next ingredient is also essential for an actual increase in productivity.

Objectives should be realistic. This is the most difficult to achieve of the four ingredients, because what may be realistic in management's view, may be unrealistic for the individual accountable for the results. This can foster 'coercion by objectives' where objectives are handed down from on high–and they'd better be achieved or else! Detroit Edison helped avoid this problem by having the employees themselves identify their own measures of productivity.

If significant, long-term improvement in productivity is desired, it must start with management effectively focusing on results. The most important resource for getting results is people. Therefore, how to effectively-get-results through people must be the vital concern of all management. IE

More than money motivates an engineer

The professional, whether an engineer or in some other field, also requires recognition and a sense of accomplishment and pride.

DONALD DEL MAR
University of Idaho
Moscow, ID

For the past two decades whenever the economy has reached *full employment* the public has been informed of an *engineering shortage* through want ads, editorials, and articles in papers, general periodicals, and engineering journals. Quarter-, half-, and full-page ads dangling the bait of high pay, an unlimited future, ideal working conditions, and professional status await those who are to be employed by company X.

A cause frequently cited by authors of articles explaining the problem is that the shortage stems from the inadequate number of engineers graduating from our nation's colleges. What is not mentioned, and is in this author's opinion of equal or greater importance, is that this shortage stems from other causes in addition to that obvious one. Many of those trained in engineering do not remain in the profession for numerous reasons, and those that do are too often ineffectively employed. This poor utilization of engineering talent stems from a lack of appreciation of the role of engineers in industry and certain organizational weaknesses, such as poor employee selection and inappropriate and ineffective motivational techniques used to attract and keep engineering talent. That the results are less than satisfactory is attributed by this author to general ignorance concerning the basics of motivation and employee perception and apathy on the part of engineering supervision and management. Like so many contemporary shortages, the engineering shortage is at least partly caused by *wasted* resources, not a shortage of resources.

Engineers not professionals

The majority of engineers employed in industry today are not professionals, notwithstanding their own contentions, those of their employers, and their membership in professional engineering societies. For those who may take exception to this, I make the following clarification. I am not saying that this majority doesn't aspire to professional status, that they don't occasionally function as professionals, that they do not approach their work in a professional (that is, a serious, responsible, and, in most cases, competent) manner, nor that some may not become professionals in the future. What I am saying is that the job demands, as determined by the company or the spervisor, do not require the individual to function as a professional. Until the job demands change, the incumbents will function in a capacity that is less than professional, i.e., as quasi-professionals.

To determine the type of treatment or change in the working environment necessary to motivate this group, we must isolate them from the masses who stand under the umbrella of professionalism. The word professional has been perverted by those in the engineering discipline itself to the point that, upon analysis, it ranks with the word *sale*. This perversion is being practiced by company recruiters, societies representing the engineering disciplines, and the general public. To define the word *Professional*, it is necessary to refer to its use in describing the first professionals–the learned professions–medicine, law, and theology-to see what common factors or characteristics are found in each that differentiate them from other activities requiring skill and training, but not professionalism.

One characteristic that is common to the learned professions is that they require the practitioner to render services that he believes to be in the best interest of the recipient–regardless of his own personal interest(s) or desires. A second common factor is that of performance evaluation: the evaluation of a professional's performance can only be measured over a long period of time. In the case of an engineer acting in a professional capacity, this evaluation is based on whether his services have fulfilled the company's needs in the past and a quantitative-qualitative judgment of his performance by other professional engineers. Evaluation of a professional on a single performance may only be done by another professional well acquainted with the area within which the work was done. A third common factor is the necessity of continuing education or professional (i.e., intellectual) growth. This continuing education may be a combination of formal and informal assimilation of information necessary to keep abreast of new ideas, views or developments in a specific discipline. Other commonly mentioned attributes of a professional include a distinctive technical language or jargon and a code of ethics with a means of enforcement.

It is recognized that there are few,

0019-8234/79/1200-0022$02.00/0

Table L Comparative summary of characteristics of engineers with varying degrees of experience.

Factor	*Nonprofessional engineer*	*Professional engineer*	*Research scientist*
Educational requirement	**College graduate BS**	**College graduate BS or MS + experience**	**College graduate PhD**
Field of endeavor	**Will be adapted to company needs**	**Probably in field trained–may be in related field**	**Same as training and/or interest**
Basis for being hired	**Ability as measured by college grades, interest, and personality**	**Probably hired as a nonprofessional in field for which the company has need**	**Interest in a particular field and/or accomplishments**
Supervision needed	**Close–until experienced**	**Little-general**	
Primary responsibility of supervision and management	**Provide clear instructions; provide coaching, fair compensation, growing opportunity if ability and needs of engineer require, and see that progress is made**	**Supply all relevant information, see that progress is made, and explain why solution is not used**	**Provide encouragement, facilities, aides, and protection from demands**
Person or group qualified to judge quality of work	**Supervisor**	**Other professionals, supervisor-over a long period of time**	**Other research scientists with experience or knowledge of field of endeavor**
Time to judge accomplishments	**Short period of time**	**Much longer than nonprofessional**	**Months to years**
Commitment of company resources	**Short period of time–small commitment**	**Long period of time–commitments may be large**	**Longest period of time and largest commitments**
Job as a primary source of satisfaction	**Generally not–some few exceptions**	**Yes–less so than research scientists**	**Yes**

if any, ideal types of engineers, but for the purpose of examination, it is convenient to isolate and describe them as such. The following descriptive summary of the quasi-professional engineer and his working environment is for the purpose of seeing, perhaps a little more clearly, those persons who represent the major group of engineers recruited by industry today to perform the skilled, semi-skilled and largely routine tasks essential to industry.

Table I is a comparative summary of the more important characteristics of quasi-professional engineers, professional engineers and engineers engaged in research. Gordon and Ross, in a thought-provoking article, "Professionals and the Corporation," used the names, Artisan Engineer, Professional and Protege, respectively for those three groups.[1]

Motivation

Motivation is a way of bringing to fruition an ability which a person already possesses. To phrase it differently, the difference between what a man does and what he is capable of doing is a problem of motivation. The following equation by Maier shows the relationship between the desired product (performance) and the ingredients (ability and motivation):'

$$\text{Performance} = \underset{\substack{\text{(Training}\\ \text{+ natural}\\ \text{capacity)}}}{\text{Ability}} \times \underset{\substack{\text{(Need}\\ \text{+ Goal)}}}{\text{Motivation}}$$

It should be noted that changing either or both of the ingredients, causes a change in performance.

In evaluating an individual engineer it is necessary to recognize not only the difference in ability to do the same job from time to time, but also his or her variable ability to do different jobs. Motivating situations or environments are as different as the individuals to be motivated, and a condemnation of an engineer's performance may be due to the failure to recognize this fact.

Referring to the formula expressing the relationships between performance, ability and motivation, we see that motivation is made up of both a need and a goal. The need, drive or desire is the condition within an individual, while the goal or incentive is an object or factor outside the individual. Both a need and goal are necessary to arouse behavior or performance, assuming the individual has the ability, and changing either the need or the goal will change the intensity of motivation. It is noteworthy that any number of needs, innate, acquired or a combination of both, may be satisfied when a goal is reached.

Needs can be classified as either innate or acquired. Innate needs, are those not dependent upon past experience and include hunger, thirst, maternal drives and sex urges. Acquired needs are those dependent upon experience. Since different people have different experiences, the needs that an individual develops are as unique as his experiences. It should be noted that understanding and respect for another acquired person's needs are least when the differences in experience are the greatest. Examples of acquired needs are the need to belong, the need to be wanted, the need to save face, the need to succeed, and the need to feel oneself an individual of importance.? This latter need is often referred to as the ego need, and is a motivator of prime importance. It is the author's opinion, for example, that ego need is the primary reason why unionization of engineers has not proceeded more rapidly.

Acquired needs are real and

"Many of those trained in engineering do not remain in the profession for numerous reasons . .."

important. The individual who foregoes his lunch to save the money for membership in the country club is sacrificing an innate need (hunger) for an acquired one (to belong, ego, etc.). The fact that comparatively few engineers join unions indicates that they are willing to accept the satisfaction of fulfilling the ego need with the feeling of professionalism and/or the status of being a part of management that company management affiliation gives them, rather than join a union to bargain for higher wages.

How an individual will react to a change in his working environment is dependent upon his perception of his present circumstances. The individual's perception of his surroundings or present circumstances are subjective in nature and may not be correct as others may perceive them. The fact that an individual feels that someone is pulling the rug from under him is reality to him and a supervisor's factual statement that no one is pulling the rug will have little, if any, effect on the individual under these circumstances. When employees, including engineering staff, perceive that off-plant social association with their supervisors and other organizational superiors or being a boot licker or yes man on the job are the surest means to promotion, you can expect that for many this will be their behavior pattern.

The strength of individual needs wanes as they are satisfied, (goal is achieved), and may become less or more important to the individual over a period of time. In our discussion it is not to be assumed that all needs of an individual must be fulfilled or that it is even desirable to do so. Referring again to our formula, we see that without a need there is no motivation and hence no performance. How hard a man will work to satisfy his needs depends on the various perceptions he holds of the goals necessary to satisfy them. Some of the factors affecting the value of goals (rewards) are:

- There must be a recognized connection between the desired performance and the goal. ".' In giving an employee a salary increase or a promotion under a merit program, much is lost to the company and the individual and his peer group if he or the group are left in doubt as to why the reward was given. A merit system pays for individual achievement resulting from the individual seeking ways or means of satisfying his needs. The performance desired by the company should be the best and the most immediate means of goal attainment perceived by the individual for satisfying his needs. In addition, if time is the only perceived connection between pay raises, it can be expected that giving a raise will have little effect on performance.
- The value of a goal varies inversely with the time perceived as necessary to obtain it. A man will work harder for a pay increase or a promotion next year than he will if he thinks the reward is years off.
- The value of a goal decreases directly as the perceived probability of obtaining it decreases.[i] The knowdedge that one man out of a group often is to be promoted to the position of group leader holds greater motivating power than if the group consisted of a hundred men. The conclusions reached by Vroom, E. E. Lawler and L. W. Porter would support this observation. However, the work of Locke[e] would raise some questions. Research by Locke, N. Cartledge and C. S. Knerr noted that dissatisfaction with performance is related to the difference between actual behavior and established goals, and that this dissatisfaction can result in higher levels of performante if the discrepancy is not too great.

Frustration as a factor

If the goal cannot be reached because the required behavior patterns are not known or cannot be found, frustration may result. When a situation exists that demands a solution and disallows a substitute goal, tension will build up within an individual, and his behavior will undergo a marked change. This change in behavior may be aggressive, regressive, fixated, or resigned in nature, or all or a combination of these at different times. Since the desired job behavior pattern for an engineer is one of solving a problem or reaching a goal, regardless of the number of new attempts required, it should be obvious that variability and resource fulness are the basic characteristics of problem-solving behavior.

Highly motivated persons who involve themselves in their work are more apt to experience frustration and exhibit what may be interpreted as temperamental or emotional behavior than those who have low levels of aspiration. The experience, training and skill of the supervisor in recognizing and effectively dealing with frustrating situations will determine whether he will succeed in decreasing the intensity and the number of such situations or whether he himself will be frustrated. A lack of such training and skill will necessitate a larger portion of the supervisor's time being spent in trying to solve these problems without actually succeeding. Then the supervisor may rationalize the situation by placing the blame on those "thin skinned, emotional, or irrational engineers who want to be pampered." Solutions to problems of frustration must, to be successful, be directed as causes rather than the resultant exhibited behavior.

Sources of job satisfaction

Individualism–the sharing to different degrees of the need for a multitude of goals—makes part of the problem of motivation one of de fining the needs and aspirations for individuals. Individualism is the reason why there cannot be a list showing the sources of satisfaction and dissatisfaction which would enable a supervisor to choose one action, response or reward that would successfully motivate all members of his group. We can, however, list those sources that are most often mentioned. Danielson, in a study of engineers and scientists, came up with the following general sources of satisfaction and dissatisfaction for nonsuperwisory engineers and scientists.[s] Satisfaction was experienced

when: they were able to start and complete a job which resulted in a feeling of accomplishment and pride; they felt that they were working on something that was challenging and required imagination and ingenuity; they were given a variety of work assignments that did not include a preponderance of disagreeable routine clerical tasks; they had a supervisor who showed that he trusted them by giving them the minimum of supervision commensurate with their ability and past performance; and they were able to gain some personal recognition for their ideas and accomplishments from their supervisor, other company personnel for whom they worked, their immediate group and groups outside the company.

Dissatisfaction was experienced when: they were required to perform tasks that were routine and repetitious, failed to utilize their various skills, or failed to provide the opportunity to prove themselves; they were required to prepare oral and written reports that were reworked, at times beyond recognition, by successive levels of supervision; they felt that the frequency, purpose, and value of the reports were often disproportionate to the time required for preparation and the value of the information communicated; they were required to perform clerical tasks; and they were required to drop a project or study before completion.

It should be pointed out that these sources of satisfaction or dissatisfaction did not represent a unanimous agreement among those engineers interviewed by Danielson; however, they were the ones most often mentioned. A review of the job characteristics mentioned most often as contributing to over-all job satisfaction indicates that they are primarily the goals sought to satisfy acquired needs. Many were concerned primarily with the ego need to feel important.

The author feels that the need for job or work completion as a source of job satisfaction or dissatisfaction is worthy of further comment. Completing a task is the goal portion of motivation. Shifting or changing of the goal, or a goal that is not clearly defined, may lead to frustration. Maier points out that task completion represents a form of motivation inherent in the nature of work and is one of the most practical ways of creating job interest.[2] The fact that an engineer is willing to forego the completion of a task or assignment at the first suggestion of his supervisor is an indication of poor motivation and lack of job interest, rather than of good discipline.

Since ego satisfaction is an important social need, it is also important to see how various forms of praise or reprimand will affect performance. The values of various ego goals are listed in decreasing order of their constructive motivating power:[9] public praise, private reprimand, public reprimand, private ridicule, private sarcasm, public ridicule, and public sarcasm. The only method of disapproval that improves performance is the private reprimand—reprimands should be handled carefully and in private.

It is often necessary to terminate a project or a line of investigation due to changes in company objectives or a change in the goal of a particular study. How does a supervisor give the engineer the satisfaction of task completion under these circumstances? You could suggest that the engineer sketch out a proposed course of action, which could be updated as more definite information becomes available. This breaks the study into definite parts or phases representing logical stopping places which, when completed, would provide goal attainment satisfaction. The engineer should be kept informed as to the future prospects of his completing the study, and, in cases where a decision is made to cancel the study, he should be told why and should be allowed to terminate the study upon completion of the phase on which he is presently working, if economically possible.

Recommendations

A number of recommendations for improving engineering staff job performance and satisfaction can be made on the basis of this discussion. The first group is for the consideration of management; the second is for supervisors of engineers.

Recommendations for management: Hire only those who will conceivably fill your anticipated requirements and whose needs are compatible with what the company is able or willing to provide in the way of recognition, opportunity, and pay.

Since the cost of training an engineer may amount to thousands of dollars, and the time from the hiring of an engineer to the time he can carry his own freight may be a year or more, it behooves management to select engineers whose education, training, skills, ambition and general outlook are compatible with what, the company needs and expects to compensate in salary, experience, job satisfaction, promotional opportunities, personal recognition, retirement and other benefits. Failure to consider these factors in selection will result in a high turnover rate. It should not be assumed, however, that those individuals that remain with a company are necessarily satisfied. Their staying may be due more to economic and family responsibilities than to any job satisfaction. In short, if companies cannot offer advancement, if they want to minimize personnel problems and if they want a low engineer turnover rate, then they should pick engineers *on* the basis of the needed ability, but only those with a low level of aspiration. When a company hires engineers with high aspiration levels and cannot provide advancement opportunities, it provides its supervisors with a problem that can never be completely solved, a situation that leads to frustration.

The selection of supervisors should be based on their training or education in the social sciences, their orientation to company goals, their willingness and ability to develop those under them and their willingness to give up engineering practice. This selection is more than picking a congenial person who doesn't rock the boat. Supervisory personnel who understand and appreciate the needs, goals and aspirations of engineers and others, who are people-oriented rather than job-oriented and who can provide the individual with a feeling of importance while still providing the company with competent, efficient engineering personnel are the ones who will on occasion rock the boat.

A job-oriented supervisor is one who sees only the immediate goal, prepares only for reaching that goal and feels that if he isn't there to guide his subordinates it will not be reached. He isn't inclined to delegate authority or, if he does, it is in name only. He doesn't fail, however, to hold people responsible or to point out their failures. He either ignores

“The evaluation of a professional’s performance can only be measured over a long period of time.”

or fails to recognize and acknowledge the contributions of others or sees them as individuals not having needs other than pay. The self-development of yes men and leg men are his contribution to the company’s future. The success of his group, being overwhelmingly dependent upon him, is replaced with disorganization or worse when he leaves. In summary, the job-oriented leader seeks to satisfy his own needs with little regard for his assistants or for the company. When he goes, he leaves behind a legacy of discontented people who may never be able to contribute their full potential.

A people-oriented supervisor is one who prepares for tomorrow by preparing today. He recognizes that the quantity and quality of output of his group exceeds his own. He sees his group not as troops, but as individuals having dissimilar as well as shared needs. He looks on his job as coaching and coordinating rather than dictating and directing. He feels that the effort and time required to develop his subordinates will result in increasing their ability and their willingness to assume greater responsibility for the quality and quantity of their work and in increasing their sense of personal accomplishment. He recognizes and exploits the compatibility of individual needs and the company goals to the benefit of both. In summary, the people-oriented supervisor doesn’t try to do his subordinates’ thinking but coaches, encourages, as well as disciplines his subordinates so that they will contribute their potential and receive the satisfaction of personal contribution while the company gets its money’s worth from its investment in personnel.

Recommendations for supervisors: Give up engineering. Your job is no longer engineering but coordinating the work of others and having your subordinates contribute their potential. Make engineers out of your people, not leg men. If you don’t want the outfit to fall apart when you are absent, consider ways and means whereby your subordinates can and will carry the ball. Acknowledge the fact that engineers are people, people with needs and aspirations, and people who contribute more in a favorable climate—with you largely determining the climate. Take the time to find out, without prying, the needs of your people and provide them, as much as possible, with the experience, training and recognition they need to do their job and yours. Don’t be afraid to try a new approach when other approaches have failed. The vast amounts of information that the social sciences have amassed have not been incorporated in the present state of the art of managing because their use entails a departure from the old, the tried and the familiar. Include, by invitation to group discussions, all the engineers who have a vested interest in the subject under consideration. The active and enthusiastic support that a project is given by an individual is directly related to how involved he is with it. If he is excluded, by purpose or oversight, in the planning or decision-making processes, he will find it very difficult to apply himself when the job requires a lot of routine work.

Our discussion has attempted to point out that if the individual engineer perceives the organization’s goals as fulfilling his needs, then both he and the organization will be satisfied. There is a definite limitation to the motivating power of the *Patent medicine* pay where money is the only motivator. The selection of engineering supervision should be based on their ability to develop their subordinates through coaching rather than re-engineering their work: their skill and training in motivating their subordinates toward common individual-organization goals. The recruiting of cream-of-the-crop and highly motivated engineers leads to dissatisfaction and high turnover in a company whose long-term needs can be realized by hiring engineers with relatively low levels of aspiration.

What is currently referred to as a shortage of engineers is nothing more than the incorrect utilization and the lack of application of motivational pinciples to the engineers we have.

addition, as the number of nonprofessional engineers increases, there will bean increased recognition by this group that, although they may be included as members of management, they actually are not, and they will demand more job security, more fringe benefits and higher pay as their price to management for foregoing the satisfaction of fulfilling such needs as individual recognition and job satisfaction.

References

[1]Gordon, Bruce F. and Ross, Ian C.; “Professionals and the Corporation;’ Research Management; Interstate Publishers, New York; Nov. 1962, Vol. V, No. 6, pp. 493-505.

Maier, N. R. F.; “Psychology in Industry” (2nd ed.); Houghton Mifflin Co., Boston, 1955.

[8]Skinner, B. F.; “Science and Human Behavior;” Macmillan, New York, 1953.

[4]Skinner, B. F.; “Beyond Freedom and Dignity;” Knopf, New York, 1971.

' Vroom, Victor; “Work and Motivation;” Wiley, New York, 1964.

I Locke, E. A.; “Toward a Theory of Task Motivation and Incentives;” ***Organizational Behavior and Human Peformance,*** March-April 1968.

Maier, N. R. F.; “Frustration: The Study of Behavior Without a Goal;” McGraw-Hill, New York, 1949, p. 264.

Danielson, Lee E.; “Characteristics of Engineers and Scientists;” Bureau of Industrial Relations, University of Michigan, Ann Arbor, 1960, pp. 33-54.

Modified from H. Moore, *Pycholo*gy for Business and Industry: Dryden, New York, 1943, p. 302. IE

Donald Del Mar is Professor, Department of Business, University of Idaho, Moscow, ID. He began his career in industry where he held various positions in engineering and management. He received a BS degree from the University of Maryland, and his MA and DBA degrees from the University of Oklahoma.

WHAT A PLANT MANAGER SHOULD EXPECT FROM INDUSTRIAL ENGINEERING

S. G. Liberty, P. E.

Chrysler Corporation

In large multi-plant manufacturing corporations, the Plant Manager is often a production oriented person who looks to industrial engineering only for time studies and direct labor man-assignments. In this type of frustrating environment, it is the responsibility of the Plant Industrial Engineer to acquaint and expose the Plant Manager to the full potential of Industrial Engineering.

The accepted definition of Industrial Engineering as formulated several years ago at a meeting of Industrial Engineering leaders in the industrial, academic, consulting and governmental fields is:

> INDUSTRIAL ENGINEERING IS CONCERNED WITH DESIGN, IMPROVEMENT, AND INSTALLATION OF INTEGRATED SYSTEMS OF MEN, MATERIALS, AND EQUIPMENT. IT DRAWS UPON SPECIALIZED KNOWLEDGE AND SKILL IN THE MATHEMATICAL, PHYSICAL, AND SOCIAL SCIENCES, TOGETHER WITH THE PRINCIPLES AND METHODS OF ENGINEERING ANALYSIS AND DESIGN, TO SPECIFY, PREDICT, AND EVALUATE THE RESULTS TO BE OBTAINED FROM SUCH SYSTEMS.

The objective of the Industrial Engineer should be to apply this definition in the operations of the plant industrial engineering activity.

In manufacturing industries, Industrial Engineering should be typified by the following functions:

1. Direct Labor Standards, Methods & Controls
2. Indirect Labor Standards, Methods & Controls
3. Other Manufacturing Expense Standards & Controls
4. Systems and Operations Analyses

The fourth function, Systems and Operations Analyses, covers a wide range of sophisticated Industrial Engineering work such as Linear Programming, PERT, Linear Regression, Simulation, etc. Under this fourth function, many of the intriguing types of analyses embodied in articles printed in the AIIE Transactions could also be included. "Models of Automatic Transfer Lines With Inventory Banks" by Buzacott and Hanifin is one such article (printed June 1978) that you may find interesting.

It is not intended that plant industrial engineers drop everything they are presently doing in order to consume themselves with the intriguing theories, problem solutions and programs espoused by the authors of these articles. On the contrary, competent industrial engineers at the plant level may not understand many of the articles printed in the Industrial Engineering Transactions because they are not responsible for industrial engineering research. The Plant Industrial Engineer should be primarily concerned with the day-to-day operating activities and problems. It is the Corporate Staff Industrial Engineers who cope with the new theories and exotic solutions of the future. The Plant Manager's job is to optimize his company's profit position by minimizing production cost through the establishment of better operating methods and controls while producing a quality product and meeting production schedules . . . and this is precisely where the Plant Industrial Engineer can show his ability.

A. DIRECT LABOR STANDARDS METHODS AND CONTROLS is probably the "bread and butter" activity of industrial engineering in manufacturing plants. This is true because most large companies operate on a standard cost system which utilizes the direct labor work standard as a basis for financial controls, variable budgets and forecasting.

In the area of direct labor, a Plant Manager should expect that his Industrial Engineering function will provide him with the following:

1. Direct Labor Work Standards realistically developed and based upon:

    Standard methods
    b. Standard tooling and equipment
    c. Standard trained operators
    d. A "fair day's work at a normal pace" concept
    e. Standard manufacturing allowances

2. The I.E. should provide man assignments by classification, covering each foreman's production area. It is not enough for the industrial engineer to merely inform the foreman how many people he should use to achieve the current production schedule. He must also be prepared to show him how the work is to be aligned on an elemental basis. In making these man assignments, Industrial Engineering should also indicate the number of relief and repairmen required to maintain scheduled production.

3. The industrial engineer should be able to advise the Plant Manager of all manpower

requirements and budget limitations for the various planned levels of operation. He should also have the knowledge and tools to provide substantial aid in determining the most effective plant operating Ievel in terms of line speeds, shift patterns and overtime utilization.

4. Industrial Engineering should have a plan for covering the utilization and control of excess manpower "on hand" because of breakdowns or other unforeseen emergencies. Why send a man home if you still have to pay him ?

5. The industrial engineer should control and approve all changes in operating manpower levels and should review all hourly wage classtification changes; in other words, he must control the labor force.

6. Industrial Engineering should establish, along with the Comptroller, a variance control program that will provide periodic meetings to:

   a. Review variance reports and assure that variance information submitted for performance reporting is valid and accurate.

   b. Supply the Plant Manager with valid explanations regarding all direct labor variance manpower.

   (A “progressive” industrial engineer should also develop a coded variance program which will lend itself to computerization so that quick feedback will be available, showing where corrective action should be concentrated.)

   It is the responsibility of the industrial engineer to point out the causes of variances and corrective solutions. There have been cases where the Production Superintendent is put on the "hot seat" and "grilled" at weekly variance meetings in an effort to determine what is causing variance in his area. But, it is the industrial engineer's job to identify the causes, propose corrective action, and coordinate the action required to eliminate variance.

   If the Production Superintendent cannot look to the industrial engineer for the reasons he has variance, then to whom should he turn? Usually he has too many production problems to devote time to such a chore.

   Production supervisors are not industrial engineers. If variance is caused by poor managerial judgment, they may try to minimize their involvement. The point is that Industrial Engineering must not only pinpoint the causes of inefficiency but must also recommend management strategies and better operating methods to help eliminate variance.

B. INDIRECT LABOR control is another important function or service that Industrial Engineering can provide. The establishment of indirect labor controls based on valid and scientifically developed standards is one of the most sought after operating controls in today's dynamic industrial plants. Historically, Industrial Engineering has emphasized the development of direct labor control techniques. Now, however, it is time to direct more effort to the task of establishing engineered control systems and methods for the purpose of improving both the economics of indirect labor operations and their effectiveness. It stands to reason that in some plants more savings can be realized from controlling indirect labor than by further methodizing direct labor operations.

Within the indirect labor function, the Plant Manager should expect Industrial Engineering to supply the following:

1. A budget manning table giving manpower authorization for various forecasted levels of operatiom These manning levels should represent the minimum indirect labor work force that can be maintained to support specified operating levels. A computerized manning table will not only facilitate quick, accurate manpower allocations, by classification, but will also facilitate horizontal and vertical comparative analysis studies. Computerization will also greatly reduce the industrial engineer's clerical routine, thereby allowing more time for analysis and problem solving.

   The manning variability must be supported by scientific analysis in order to validate the applicable work criteria that affect each indirect labor classification within the plant. In other words, it is not enough to say that we need additional indirect labor people as production increases, because this is not true in all cases. For example, the number of Plant Protection personnel required is not necessarily based upon production volume. Plant policy, the number of tours required or the number of operating shifts will affect the manpower level of the Plant Protection function more significantly than a 10% change in production volume. By the same token, the Production Control expediting function is affected more by an increase in total parts required due to a product engineering change than by an increase in production volume. The area of determining the work load criteria or determinants, is one that is currently in need of some sound Industrial Engineering spade work.

2. The industrial engineer should work with the foreman and supervisor in man-assigning all areas within the plant as workload factors increase or decrease.

3. The I.E. should maintain a current manning table reflecting all changes to the plant

operation, with backup by category for the current operating year. He should also have a formal audit program to check a selected number of indirect labor operations so that he can note any new methods informally instituted by production *management.*

4. A formal variance program should be maintained so that valid explanations can be provided as to why variance exists and what is being done to eliminate the causes.

5. Industrial Engineering must approve all indirect labor requisitions and review wage classification change notices and reinstatement for indirect labor transactions.

One of the problems encountered by many attempting to install an indirect labor program is that they try to start out with complicated and refined indirect labor techniques. This common mistake is due to the fact that most articles and lectures covering indirect labor control techniques contain complicated procedures and formulae aimed at improving established programs. However, can anyone actually use these techniques in a plant that has never had effective indirect labor controls ? Ask yourself this question: "Do you have the time to spend in developing involved techniques, or is it more important that you establish immediate controls and a good working base before moving out with the more refined methods ?" Plant management wants results today -- not next year.

C. OTHER MANUFACTURING EXPENSE STANDARDS, the third function, *is an* area that many seem to be avoiding. In my opinion, it is an area rich in potential for quick savings because the problem of union confrontation is minimized. "Other Manufacturing Expense" (OME) means expense, other than labor, i.e. perishable tools, maintenance materials, supplies, scrap and rework costs, etc.

1. The Plant Manager should expect that Industrial Engineering will at least make an analysis of "actual" non-productive dollar expenditures so that the high cost items may be identified and studied to determine the economic feasibility of establishing usage standards. A good rule of thumb is that 20% of the non-productive material items contribute to 80% of the expense in this category. Consequently, it should be expected that some type of usage standards and control will be applied to the high cost items.

2. The industrial engineer should work with each supervisor to establish material usage standards and better methods of operation. Each supervisor should be informed, in writing, of material usage standards that apply to his area and the weekly authorization as determined by production schedules.

3. The industrial engineer should participate in the plant reclamation and salvage programs for non-productive material. He should also determine the rework labor cost and assist Production Control and Quality Control in determining the appropriate scrap or salvage action to be taken for production material as well.

4. Industrial Engineering should review all work orders and requisitions for purchased services and conduct periodic investigations on a selected basis to determine whether long established purchased services can be economically brought in-house because of new methods developments.

5. The industrial engineer should supply the Plant Manager with explanations regarding all significant OME variances along with recommended corrective action.

6. Industrial Engineering must participate in all programs emphasizing the conservation of utilities, power and fuel consumption.

In the area of OME, the important thing to remember is that only the significant expenditures should be controlled. It would be nice to have 100% coverage but not at the expense of neglecting the daily operating problems that are in need of immediate action.

D. SYSTEMS AND OPERATIONS ANALYSIS means more than just studying the organizational structure, making recommendations and drawing charts. It means understanding computerized management techniques to the extent that meaningful operating plans and projections can be provided to facilitate accurate forecasts.

Accurate and detailed forecasting is the mainstay of forward planning for effective manpower and resource utilization, as well as capital expendiure determination and profit planning.

The development of a computer system to enable plant management to better determine their monthly manufacturing operating plan and corresponding expense forecast appears mandatory if we are to improve forecasting at the grass roots level.

Currently, many plant operating plans are developed manually. The amount of clerical work involved in the manual generation prohibits thorough evaluation of alternative plans, and often prevents the establishment of detailed department level objectives to support the total plan.

By assigning the computational effort to the computer, management has the capability to:

1. Quickly evaluate alternative operating plans involving changes in manning, overtime, production rates, etc.

2. Determine the economic effect of simulated alternative plans.

3. Segment the total plan into departmental objectives for optimum control purposes.

Two problems are often encountered in trying to introduce computerized I. E. techniques at the plant level:

1. Plant operating management often does not have the patience nor inclination to understand and encourage the adoption of computerized methodology for handling “daily" operating problems and short range projections.

2. Many plant industrial engineering functions are not capable of supplying a scientific approach toward solving operating problems nor can they supply computerized programs that can expeditiously provide numerous alternate plans for management consideration.

The first step that must be taken to rectify this situation is to reorganize at the Corporate level and to create a Corporate Industrial Engineering Systems activity. The objective of such an organization is to train plant industrial engineers while at the same time developing analytical and control programs utilizing the latest scientific technology.

"Simulation" "Linear Programming", and "Linear Regression", are terms that have been around for a number of years, but unless the technology is actually used in an on-the-job situation, the application is not understood.

Using simulation to increase productivity on a transmission case transfer line; or linear programming to determine the least expensive cupola charge mix; or linear regression analysis to establish manpower determinants are examples of the kinds of efforts worth undertaking. Working with the plant industrial engineers to establish plant computer files for testing these programs is the most effective way of providing on-the-job training while at the same time building a high confidence level in the validity of the new technology and its output.

In summary, the Plant Manager should look to his Industrial Engineering function for:

1. Valid operating standards

2. Effective man-assigning and manpower controls

3. Objective analysis and determination of variance cost

4. Solutions to operating problems through the development of better methods and systems using computerized technology

5. Effective implementation of new methods and systems supplemented with technical training seminars and scheduled follow-up

6. Accurate forecasting

7. Effective salesmanship

Perhaps the most important function of those summarized above, and one that the Plant Manager should automatically expect, is that of “salesmanship”. If the industrial engineer can effectively implement his programs without continually requiring the strong arm of the Plant Manager, it not only improves his effectiveness, but also it identifies him as an industrial engineer with top management potential.

BIOGRAPHICAL SKETCH

SOTER (ART) LIBERTY is the manager of the Chrysler Corporate Industrial Engineering Systems Department. Mr. Liberty is currently responsible for developing Operations Planning and Control Systems (OPACS) and for establishing management techniques to facilitate technical and administrative productivity through the use of time sharing and mini-computer applications.

Previously, he was a manager of Industrial and Systems Engineering, General Manufacturing Division. In this capacity his responsibilities included work standards and manpower control; non-productive material usage standards and inventory control; and systems applications for time sharing and mini-computers for the sixteen plants of the division.

He has taught courses in management sciences at Wayne Sate University and Macomb County Community College. Currently, he is teaching Industrial Engineering at the Chrysler Institute. He has a B. S. from the University of San Francisco and an M. B. A. in Industrial Management from the University of California (Berkley) where he received his key from the Beta Gamma Sigma Honor Society. He is a registered Professional Engineer.

Contact at: Chrysler Corporation
CIMS 417-20-04
P. O. Box 1919
Detroit, MI 48288

(313) 956-1966

RESTRUCTURING THE INDUSTRIAL ENGINEERING DEPARTMENT OBJECTIVES

By Jerry D. McCormick
Director of Manufacturing
Sperry Vickers AMD Division
Jackson, Mississippi

"Induce your competitors not to invest in those products, markets, and services where you expect to invest the most."

That is the fundamental rule of business strategy. To do this successfully requires the three vocational areas of Marketing, Engineering Design, and Industrial Engineering; these specialties, of course, being market development, product development and production capability development. The author takes a look at some weaknesses of the traditional I. E. organization to satisfy this fundamental strategy. He also suggests a new idea for restructuring Industrial Engineering to achieve parity with Marketing and Engineering in contribution to business strategies.

Have you ever had this experience: Sales are up, profits are acceptable, no serious business threat exists, everything is fine on the home front, your golf and tennis games are improving, and yet, you wake up from a deep sleep with an uneasy feeling that something bad is about to happen?

Psychologists call if "free floating anxiety" because it arises, not from any definable emergency you can put your finger on, but-from an uneasiness without focus. It strikes quite often when things seem rosiest. You worry without knowing exactly why you worry. This, I believe, is the mood of industry today.

Industrial Engineering is unable to do much about worries such as inflation, national unemployment, social problems and stock market dips. There is a long list of related business problems that are subject to Industrial Engineering influence. Some of these are: the leveling off of productivity in industrial plants, the lack of business growth without acquisitions, the lack of adequate return on assets in capital intensive businesses, lack of new products for market diversification, lack of a solution to conflicts in basic competitive strategies (for instance, conflicts between high profit margins versus reinvestment strategies) . Industrial Engineering managers could have uneasy feelings in these areas since most Industrial Engineering objectives don't address the firms' strategic problems.

The fact is that in manufacturing companies, the majority of assets employed, capital invested, people employed, and use of operating funds are in the operations side of the business. The use of these resources must be organized, planned and controlled in such a way as to strengthen the firm. Problems and pressures facing manufacturing companies ultimately find their way to the Industrial Engineering Department where they must be dealt with through some sort of organization. First let's review the traditional approach and then take a look at another idea.

TRADITIONAL ORGANIZATION

The traditional organization of the Industrial Engineering Department having responsibilities for standards, methods, processes, tooling, numerical control programming, etc., led to the Department developing a Methods and Standards group; a Process Control group; a Tool Design group; a Numerical Control Programming group and so on as shown in Figure 1.

TRADITIONAL ORGANIZATION
FUNCTION FOCUSED

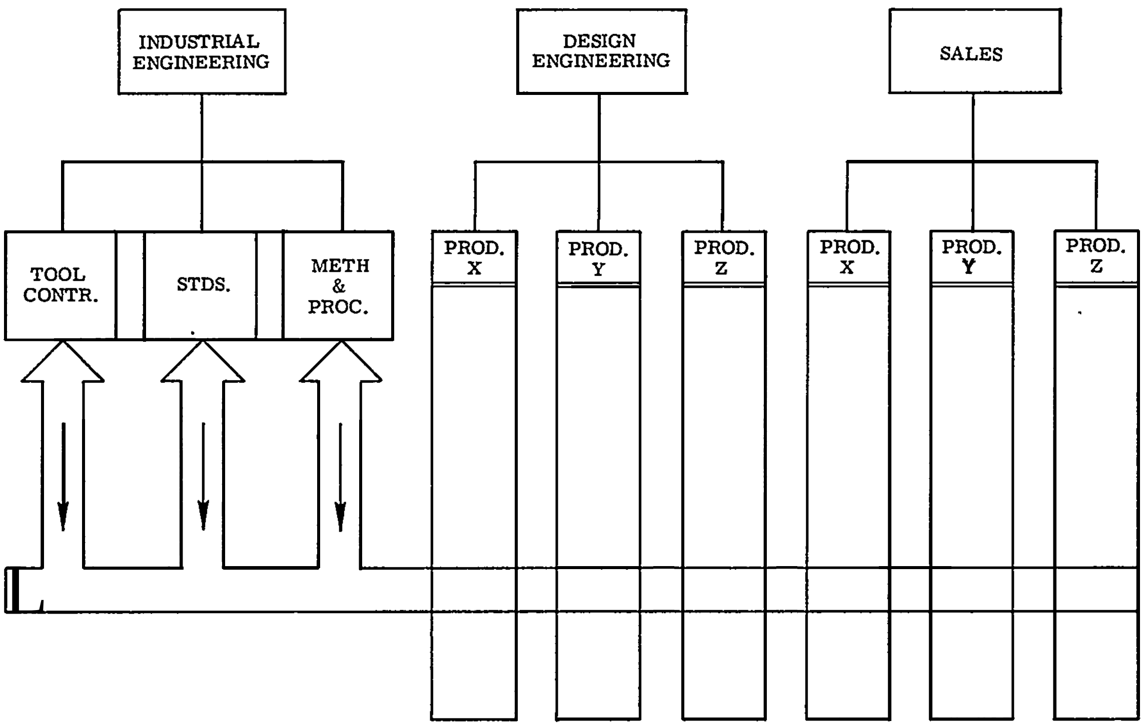


FIG. 1

This traditional structure is not all bad as it is based upon sound management theories, such as, specialization, line and staff relations, authority and responsibility and span of control. However, this type of organization has several weaknesses. When it is involved in multiple projects, conflicts invariably arise over the relative priorities of these projects. Also , this organization places more emphasis on Industrial Engineering's specialty rather than the goals of the business (the goals of the business being, market penetration. increasing sales. increasing profits. etc.) . In today's rapidly changing and highly visible business environment, the traditional organization does not allow sufficient involvement of Industrial Engineering to maintain motivation and inertia to the degree of other functions, such as, Marketing, Engineering, and Materials Management. This lack of involvement contributes to the uneasy feeling that something bad is about to happen.

STRATEGIES UNITE ORGANIZATIONS

A better way of structuring the Industrial Engineering organization exists and I believe it must revolve around the business strategies. Nowhere have I seen any business strategy which included methods, standards, process control, tooling, and N. C. programming. In fact, if the strategies are properly stated, they probably do not include words like cost reduction, value analysis and operational improvements. Most manufacturing companies' business strategies do include these four items: (1) Business Development, (2) Market Development, (3) Product Development, and, (4) Selection of Competitive Strategies.

From this, it is clear that we need to start closing on an Industrial Engineering change to refocus organizations and objectives. You can start closing on the design for your department by analyzing the focus of the

business organization. Almost all manufacturing companies are either product-focused organizations, or market-focused organizations. (Note: For those businesses not having a clearly focused organization and business strategy, this should be the number one goal of management. Industrial Engineering should be in a position to help lead this effort.)

Flost organizations have thought through their business and have established the focus for the organization and the business strategies. Over a period of time, the strategies are reinforced by trade-off decisions. From these trade-off decisions comes the business mission. It almost always emphasizes one of these competitive parameters: price, quality, credibility (dependability to satisfy total customer needs) , or production flexibility. It is not my purpose to dwell upon business strategies or the process of strategic planning. There is a mountain of material on the subject and I'll mention just one example: The Boston Consulting Group pamphlets covering all fundamental aspects of strategy. All Industrial Engineering managers should be well versed in the area of strategic planning. When you are, you can assess the organizational mission or focus and determine how Industrial Engineering can be restructured to contribute to the achievement of the business strategies.

RESTRUCTURED ORGANIZATION

An example of a restructured Industrial Engineering organization when the business organization and strategy are product-focused is shown in Figure 2.

In its simplest form, the restructured organization has Industrial Engineering supervisors for each product line. The supervisors and their group are accountable for all Industrial Engineering functions within the product line. Each group will have counterparts within Marketing, Engineering and perhaps throughout the functional organization.

Authority in this organization is decentralized and new product intro-

RESTRUCTURED ORGANIZATION
PRODUCT FOCUSED

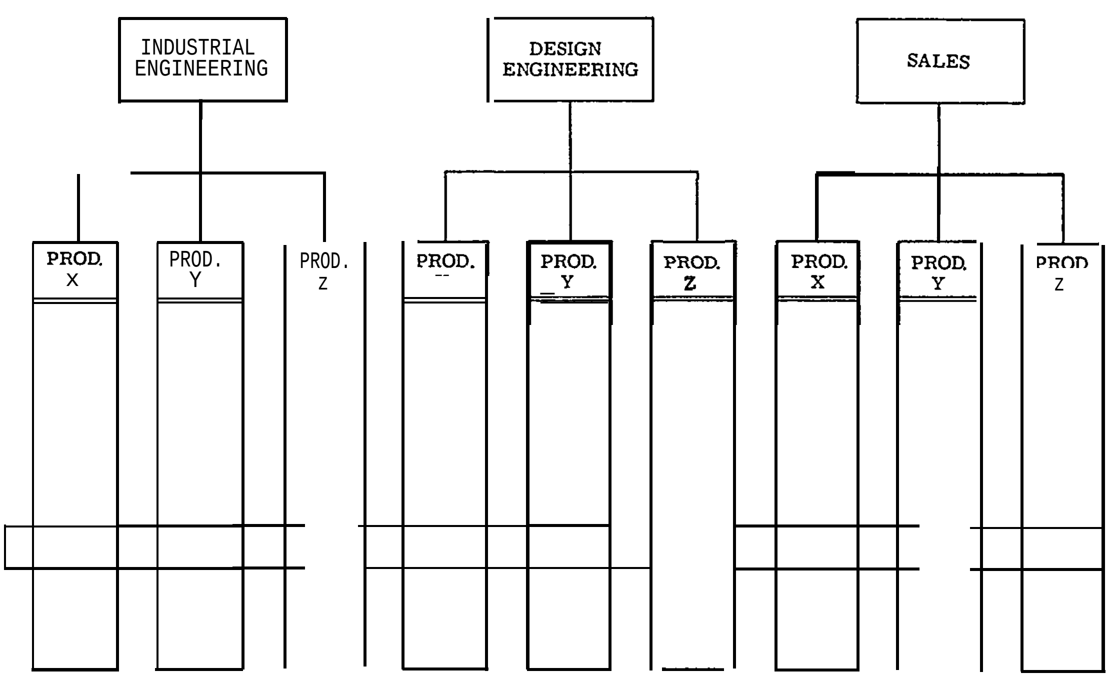


FIG. 2

duction is enhanced by this flexibility. Each product group has independence and thus moves quickly to satisfy market and product development needs.

EFFECTIVENESS REQUIRES FOCUS

The success of the business strategies, in any product line, revolves around superiority of market share and cost-price relationships compared to competitors. The three business oriented areas of Marketing, Engineering, and Industrial Engineering are the prime functions to focus on these relationships. In addition to their vocational contribution, a strong team effort between these product-focused groups in Marketing, Engineering and Industrial Engineering is needed. This unity of purpose creates espirit de corps and helps to eliminate frustration, improve communications and clarify objectives.

It should be easy to see that this product-focused team is in a strong position to determine the critical issues facing the product line and to prepare plans and take actions to achieve the business strategies -- whether these strategies call for new markets, new models, increased market penetration, or any of a variety of other strategies which will directly or indirectly keep your competitors from investment in your area of interest.